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DOES HAZARDOUS WASTE MATTER? EVIDENCE FROM THE HOUSING MARKET AND THE SUPERFUND PROGRAM

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Abstract

This paper uses the housing market to develop estimates of the local welfare impacts of Superfund sponsored clean-ups of hazardous waste sites. We show that if consumers value the clean-ups, then the hedonic model predicts that they will lead to increases in local housing prices and new home construction, as well as the migration of individuals that place a high value on environmental quality to the areas near the improved sites. We compare housing market outcomes in the areas surrounding the first 400 hazardous waste sites chosen for Superfund clean-ups to the areas surrounding the 290 sites that narrowly missed qualifying for these clean-ups. We find that Superfund clean-ups are associated with economically small and statistically indistinguishable from zero local changes in residential property values, property rental rates, housing supply, total population, and the types of individuals living near the sites. These findings are robust to a series of specification checks, including the application of a quasi-experimental regression discontinuity design based on knowledge of the selection rule. Overall, the preferred estimates suggest that the local benefits of Superfund clean-ups are small and appear to be substantially lower than the $43 million mean cost of Superfund clean-ups.

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Introduction

The estimation of individuals' valuations of environmental amenities with revealed preference methods has been an active area of research for more than three decades. There are now theoretical models outlining revealed preference methods to recover economically well defined measures of willingness in a variety of settings, including housing markets, recreational choices, health outcomes, and the consumption of goods designed to protect individuals against adverse environmentally-induced outcomes (Freeman 2003 and Champ, Boyle, and Brown 2003 contain reviews). The application of these approaches, however, is often accompanied by seemingly valid concerns about misspecification that undermine the credibility of any findings. Consequently, many are skeptical that markets can be used to determine individuals' valuations of environmental amenities.[1]

Hazardous waste sites are an example of an environmental disamenity that provokes great public concern. The 1980 Comprehensive Environmental Response, Compensation, and Liability Act, which became known as Superfund, gave the EPA the right to place sites that pose an imminent and substantial danger to public welfare and the environment on the National Priorities List (NPL) and to initiate remedial clean-ups at those sites. Through 2005, approximately \$35 billion (2005\$) in federal monies and an unknown amount of private funding has been spent on Superfund clean-ups, and yet remediations are incomplete at roughly half of the nearly 1,600 sites.[2] The combination of these high costs and the absence of convincing evidence of its benefits has made Superfund a controversial program (EPA 2006).

This paper uses the housing market to estimate the welfare consequences of Superfund sponsored clean-ups of hazardous waste sites. The empirical challenge is that the evolution of housing prices proximate to the Superfund sites in the absence of the clean-ups is unknown. The development of a valid counterfactual is likely to be especially challenging, because the sites assigned to the NPL are the most polluted ones in the US. For example, what would have happened to housing prices in Love Canal, NY, in the absence of the famous Superfund clean-up there?

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[1] Further, the increasing reliance on stated preference techniques to value environmental amenities is surely related to dissatisfaction with the performance of revealed preference techniques. See Hanemann (1994)) and Diamond and Hausman (1994) for discussions of stated preference techniques.
[2] Throughout the paper, monetary figures are reported in 2000 \$'s, unless otherwise noted.

To solve this problem, we implement a quasi-experiment based on knowledge of the selection rule that the EPA used to develop the first NPL in 1983. The EPA was only allocated enough money to conduct 400 clean-ups. After cutting the list of candidate sites from 15,000 to 690, the EPA invented and implemented the Hazardous Ranking System (HRS) that assigned each site a score from 0 to 100 based on the risk it posed, with 100 being the most dangerous. The EPA placed the 400 sites with HRS scores exceeding 28.5 on the initial NPL in 1983, making them eligible for Superfund remedial clean-ups. We compare the evolution of housing market outcomes between 1980 and 2000 in areas near sites that had initial HRS scores above and below the 28.5 threshold. We also implement a regression discontinuity design (Cook and Campbell 1979) to focus the comparisons among sites with scores near the threshold.

To structure the analysis, we model the consequences of a quasi-experiment that leads to an exogenous change in a local amenity in the context of the hedonic method (Freeman 1974; Rosen 1974). We show that if consumers value the clean-ups, then there are two empirical predictions. First, the improvement at the site should lead to increases in the demand and supply of local housing and, in turn, increases in the prices and quantities of houses. Second, the improvement should lead to sorting such that the share of the population living near the improved sites that places a high value on environmental quality increases. The implication is that an exclusive focus on housing prices as in previous quasi-experimental hedonic studies (Chay and Greenstone 2005; Linden and Rockoff 2006) may obscure part of the welfare gain.

The results suggest that individuals place a small value on a hazardous waste site's inclusion on the NPL and subsequent clean-up. Specifically, we find that a site's placement on the NPL is associated with economically small and statistically indistinguishable from zero local changes in residential property values, property rental rates, housing supply, total population, and the types of individuals living near the site. These findings are robust to a wide variety of specification checks, and they hold whether they are measured 7 (in 1990) or 17 (in 2000) years after placement on the NPL. Overall, these findings suggest that the mean local benefits of a Superfund clean-up as measured through the housing market are substantially lower than our estimated average cost of $43 million per Superfund clean-up.

The conventional hedonic approach compares areas surrounding NPL sites with the remainder of

the US. In contrast to the HRS research design, the conventional approach produces estimates that suggest that gains in property values exceed the mean costs of clean-up. However, these regressions also produce a number of puzzling results that undermine confidence in the approach's validity. Further, there is evidence that the conventional approach is likely to confound the effect of the presence of a NPL site with other determinants of housing market outcomes. Notably, the HRS research design appears to greatly reduce the confounding.

The study is conducted with the most comprehensive data file ever compiled by the EPA or other researchers on the Superfund program and its effects. The resulting database has information on all 1,400 Superfund hazardous waste sites as of 2000, the sites that narrowly missed placement on the initial NPL, and census-tract level housing market outcomes for 1980 (before the release of the first NPL), 1990, and 2000. Consequently, this study is a substantial departure from the previous Superfund/hazardous waste site hedonic literature, which is entirely comprised of examinations of one or a handful of sites and collectively covers just 30 different sites (Schmalensee et al. 1975; Michaels and Smith 1990; Kohlhase 1991; Kiel 1995; Gayer, Hamilton, and Viscusi 2000 and 2002; Kiel and Zabel 2001; McCluskey and Rausser 2003; Ihlanfeldt and Taylor 2004; Messer et al. 2004; and Farrell 2004).[3]

The paper proceeds as follows. Section I provides background on the Superfund program and how the HRS research design may allow for credible estimation of the effects of Superfund clean-ups on housing market outcomes. Section II discusses how to use hedonic theory to provide an economic interpretation for the results from the HRS research design. Section III details the data sources and provides some summary statistics. Sections IV and V report on the econometric methods and empirical findings, respectively. Section VI interprets the results, while VII concludes.

I. The Superfund Program and a New Research Design

[3] Using EPA estimates of the probability of cancer cases and the costs of Superfund clean-ups, Viscusi and Hamilton (1999) find that at the median site expenditure the average cost per cancer case averted by the clean-up exceeds $6 billion. This health effects approach requires knowledge of the toxics present and the pathways they travel, the health risk associated with a toxic by pathway pair, the size of the affected population, the pathway-specific exposure, and the willingness to pay to avoid mortality/morbidity. Due to the state of scientific uncertainty associated with each step, we think this approach is unlikely to produce credible benefit estimates.

A. History and Broad Program Goals

Before the regulation of the disposal of hazardous wastes by the Toxic Substances Control and Resource Conservation and Recovery Acts of 1976, industrial firms frequently disposed of wastes by burying them in the ground. Love Canal, NY is perhaps the most infamous example of these disposal practices. Throughout the 1940s and 1950s, this area was a landfill for industrial waste, and more than 21,000 tons of chemical wastes were ultimately deposited there. After New York state investigators found high concentrations of dangerous chemicals in the air and soil at Love Canal, concerns about the safety of this area prompted President Carter to declare a state of emergency in 1978 that led to the relocation of the 900 residents. The Love Canal incident helped to galvanize support for addressing the legacy of industrial waste, and this led to the creation of the Superfund program in 1980.

The centerpiece of the Superfund program, and this paper's focus, is the long-run remediation of hazardous waste sites.[4] These multi-year remediation efforts aim to reduce permanently the serious, but not imminently life-threatening, dangers caused by hazardous substances. 1,552 sites have been placed on the NPL by the end of 2005 and thereby chosen for these long-run clean-ups. The next subsection describes the selection process, which forms the basis of our research design.

B. Site Assessment & Superfund Clean-Ups Processes

As of 1996, more than 40,000 hazardous waste sites had been referred to the EPA for possible inclusion on the NPL. Since there are limited resources available for these clean-ups, the EPA follows a multi-step process to identify the most dangerous sites.

The final step of the assessment process is the application of the Hazardous Ranking System (HRS), which is reserved for the most dangerous sites. The EPA developed the HRS in 1982 as a standardized approach to identify the sites that pose the greatest threat to humans and the environment. The original HRS evaluated the risk for exposure to chemical pollutants along three migration

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[4] The Superfund program also funds immediate removals, which are short-term responses to environmental emergencies aimed at diminishing an immediate threat. These actions are not intended to remediate the underlying environmental problem and are not exclusive to hazardous waste sites on the NPL.

'pathways': groundwater, surface water, and air. The major determinants of risk along each pathway for a site are the toxicity and concentration of chemicals present, the likelihood of exposure and proximity to humans, and the size of the potentially affected population. The non-human impact is also considered but plays a minor role in determining the HRS score.

The HRS produces a score that ranges from 0 to 100, with 100 being the highest level of risk. From 1982-1995, the EPA assigned all hazardous waste sites with a HRS score of 28.5 or greater to the NPL. These sites are the only ones that are eligible for Superfund remedial clean-up. The Data Appendix provides further details on the determination of HRS test scores and their role in assignment to the NPL.

Once a site is placed on the NPL, it generally takes many years until clean-up is complete. The first step is a further study of the extent of the environmental problem and how best to remedy it. This assessment is summarized in the Record of Decision (ROD), which also outlines the clean-up actions that are planned for the site. The site receives the "construction complete" designation once the physical construction of all clean-up remedies is complete, the immediate threats to health have been removed, and the long-run threats are "under control." The final step is the site's deletion from the NPL.

C. 1982 HRS Scores as the Basis of a New Research Design

This paper's goal is to obtain reliable estimates of the effect of Superfund sponsored clean-ups of hazardous waste sites on housing market outcomes in areas surrounding the sites. The empirical challenge is that NPL sites are the most polluted in the US, so it is likely that there are unobserved factors that covary with both proximity to hazardous waste sites and housing prices. Although this possibility cannot be tested directly, it is notable that proximity to a hazardous waste site is associated with lower population densities, lower household incomes, higher percentages of high school dropouts, and a higher fraction of mobile homes among the housing stock.

Consequently, cross-sectional estimates of the association between housing prices and proximity to a hazardous waste site may be severely biased due to omitted variables.[5] In fact, the possibility of

[5] Cross-sectional models for housing prices have exhibited signs of misspecification in a number of other settings,

confounding due to unobserved variables has been recognized as a threat to the use of the hedonic method to develop reliable estimates of individuals' willingness to pay for environmental amenities since its invention (Small 1975). This paper's challenge is to develop a valid counterfactual for the housing market outcomes near Superfund sites in the absence of their placement on the NPL and clean-up.

A feature of the initial NPL assignment process that has not been noted previously by researchers may provide a credible solution to the likely omitted variables problem. In the first year after the legislation's passage, 14,697 sites were referred to the EPA and investigated as potential candidates for remedial action. Through an initial assessment process, the EPA winnowed this list to the 690 most dangerous sites. Although the Superfund legislation directed the EPA to develop a NPL of "at least" 400 sites (Section 105(8)(B) of CERCLA), budgetary considerations caused the EPA to set a goal of placing exactly 400 sites on the NPL.

The EPA developed the HRS to provide a scientific basis for determining the 400 out of the 690 sites that posed the greatest risk. Pressured to initiate the clean-ups quickly, the EPA developed the HRS in about a year. It was applied to the 690 worst sites, and their scores were ordered from highest to lowest. A score of 28.5 divided numbers 400 and 401, so the initial NPL published in September 1983 was limited to sites with HRS scores exceeding 28.5. See the Data Appendix for further details.

The central role of the HRS score provides a compelling basis for a research design that compares housing market outcomes near sites with initial scores above and below the 28.5 cut-off for at least three reasons. First, it is unlikely that sites' HRS scores were manipulated to affect their placement on the NPL, because the 28.5 threshold was established <u>after</u> the testing of the 690 sites was completed. The HRS scores therefore reflected the EPA's assessment of the risks posed by each site and were <u>not</u> based on the expected costs or benefits of clean-up.

Second, the HRS scores are noisy measures of risk, so it is possible that true risks are similar

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including the relationships between land prices and school quality, air pollution, and climate variables (Black 1999; Chay and Greenstone 2005; Deschenes and Greenstone 2006). Incorrect choice of functional form is an alternative source of misspecification (Halvorsen and Pollakowski 1981; Cropper et al. 1988). Other potential sources of biases of published hedonic estimates include measurement error and publication bias (Black and Kneisner 2003; Ashenfelter and Greenstone 2004).

above and below the threshold. This noisiness was a consequence of the scientific uncertainty about the health consequences of exposure to the tens of thousands of chemicals present at these sites.[6] Further, there wasn't any evidence that sites with HRS scores below 28.5 posed little risk to health. The Federal Register specifically reported that the "EPA has not made a determination that sites scoring less than 28.50 do not present a significant risk to human health, welfare, or the environment" and that a more informative test would require "greater time and funds" (Federal Register, September 21, 1984).[7]

Third, the selection rule that determined placement on the NPL is a highly nonlinear function of the HRS score, which allows for a quasi-experimental regression discontinuity design. Specifically, we will compare outcomes at sites "near" the 28.5 cut-off. If the unobservables are similar or changing smoothly around the regulatory threshold, then it is possible to make causal inferences.[8]

An additional feature of the analysis is that an initial score above 28.5 is highly correlated with eventual NPL status but is not a perfect predictor of it. This is because some sites were rescored, with the later scores determining whether they ended up on the NPL.[9] The subsequent analysis uses an indicator variable for whether a site's initial (i.e., 1982) HRS score was above 28.5 as an instrumental variable for whether a site was on the NPL in order to purge the potentially endogenous variation in NPL status.

Finally, it important to emphasize that sites that failed to qualify for the NPL were ineligible for Superfund remediations. We investigated whether these sites were cleaned-up under state or local

[6] A recent history of Superfund's makes this point. "At the inception of EPA's Superfund program, there was much to be learned about industrial wastes and their potential for causing public health problems. Before this problem could be addressed on the program level, the types of wastes most often found at sites needed to be determined, and their health effects studied. Identifying and quantifying risks to health and the environment for the extremely broad range of conditions, chemicals, and threats at uncontrolled hazardous wastes sites posed formidable problems. Many of these problems stemmed from the lack of information concerning the toxicities of the over 65,000 different industrial chemicals listed as having been in commercial production since 1945" (EPA 2000, p. 3-2).

[7] One way to measure the crude nature of the initial HRS test is by the detail of the guidelines used for determining the HRS score. The guidelines used to develop the initial HRS sites were collected in a 30 page manual. Today, the analogous manual is more than 500 pages.

[8] The research design of comparing sites with HRS scores "near" the 28.5 is unlikely to be valid for sites that received an initial HRS score after 1982. This is because once the 28.5 cut-off was set, the HRS testers were encouraged to minimize testing costs and simply determine whether a site exceeded the threshold. Consequently, testers generally stop scoring pathways once enough pathways are scored to produce a score above the threshold.

[9] As an example, 144 sites with initial scores above 28.5 were rescored and this led to 7 sites receiving revised scores below the cut-off. Further, complaints by citizens and others led to rescoring at a number of sites below the cut-off. Although there has been substantial research on the question of which sites on the NPL are cleaned-up first (see, e.g., Sigman 2001), we are unaware of any research on the determinants of a site being rescored.

programs and found that they were frequently left untouched. Among the sites that were targeted by these programs, a typical solution was to put a fence around the site and place signs indicating the presence of health hazards. The point is that the remediation activities at NPL sites drastically exceeded the clean-up activities at non-NPL sites in scope and cost.

II. Using Hedonics to Value Changes in Local Environmental Quality Due to Superfund Clean-ups

An explicit market for a clean local environment does not exist. The hedonic price method is commonly used to infer the economic value of non-market amenities like environmental quality to individuals. To date, its empirical implementation has generally been in cross-sectional settings where it is reasonable to assume that consumers and producers have already made their optimizing decisions. This section briefly reviews the cross-sectional equilibrium. It then discusses how an improvement in local environmental quality due to a Superfund clean-up leads agents to alter their utility and profit-maximizing decisions and the resulting new equilibrium. The purpose of this discussion is to devise an empirical strategy to infer the welfare consequences of Superfund clean-ups using decennial Census data.

A. A Brief Review of Equilibrium in the Hedonic Model

Economists have estimated the association between housing prices and environmental amenities at least since Ridker (1967) and Ridker and Henning (1967). However, Rosen (1974) and Freeman (1974) were the first to give this correlation an economic interpretation. In the Rosen formulation, a differentiated good is described by a vector of its characteristics, $\mathbf{C} = (c_1, c_2, \ldots, c_n)$. In the case of a house, these characteristics may include structural attributes (e.g., number of bedrooms), neighborhood public services (e.g., local school quality), and local environmental amenities (e.g., distance from a hazardous waste site). Thus, the market price of the i^{th} house can be written as:

(1) $P_i = P(c_{i1}, c_{i2}, \ldots, c_{in})$.

The partial derivative of $P(\bullet)$ with respect to the j^{th} characteristic, $\partial P/\partial c_j$, is referred to as the marginal implicit price. It is the marginal price of the j^{th} characteristic implicit in the overall price of the house, holding constant all other characteristics.

In the hedonic model, the locus between housing prices and a characteristic, or the hedonic price schedule (HPS), is generated by the equilibrium interactions of consumers and producers. It is assumed that markets are competitive, all consumers rent one house at the market price, and utility depends on consumption of the numeraire, X (with price equal to 1), and the vector of house characteristics:

(2) $u = u(X, \mathbf{C})$.

The budget constraint is expressed as $I - P - X = 0$, where I is income.

Maximization of (2) with respect to the budget constraint reveals that individuals choose levels of each of the characteristics to satisfy $(\partial U/\partial c_j) / (\partial U/\partial x) = \partial P/\partial c_j$. Thus, the marginal willingness to pay for c_j (e.g., local environmental quality) must equal the marginal cost of an extra unit of c_j in the market.

It is convenient to substitute the budget constraint into (2), which gives $u = u(I - P, c_1, c_2, \ldots, c_n)$. By inverting this equation and holding all characteristics of the house but j constant, an expression for willingness to pay for c_j is obtained:

(3) $B_j = B_j\,(I - P, c_j, \mathbf{C}_{-j}^{*}, u^{*})$.

Here, u^{*} is the highest level of utility attainable given the budget constraint and $\mathbf{C}_{-j}^{*}$ is the optimal quantities of other characteristics. This is referred to as a bid (or indifference) curve, because it reveals the maximum amount that an individual would pay for different values of c_j, holding utility constant.

Heterogeneity in individuals' bid functions due to differences in preferences and/or incomes leads to differences in the chosen quantities of a characteristic. This is depicted in Figure 1a, which plots the HPS and bid curves for c_j of three consumer types. The consumers are denoted as types #1, #2, and #3, and potentially there are an unlimited number of each type. Each bid function reveals the standard declining marginal rate of substitution between c_j and X (because $X = I - P$). The three types choose houses in locations where their marginal willingness to pay for c_j is equal to the market determined marginal implicit price, which occur at c_j^1, c_j^2, and c_j^3, respectively. Given market prices, these consumers' utilities would be lower at sites with higher or lower levels of local environmental quality.

The other side of the market is comprised of suppliers of housing services. We assume that suppliers are heterogeneous due to differences in their cost functions. This heterogeneity may result from differences in the land they own. For example, it may be very expensive to provide a high level of local

environmental quality on a plot of land located near a steel factory. By inverting a supplier's profit function, we can derive its offer curve for the characteristic c_j:

(4) $O_j = O_j\,(c_j, \mathbf{C}_{-j}^{*}, \pi^{*})$,

where π^* is the maximum available profit given its cost function and the HPS. Figure 1a depicts offer curves for three types of suppliers. With this set-up, individuals that live in a house that they own would be both consumers and suppliers and their supplier self would rent to their consumer self.

The HPS is formed by tangencies between consumers' bid and suppliers' offer functions. At each point on the HPS, the marginal price of a housing characteristic is equal to an individual's marginal willingness to pay for that characteristic and an individual supplier's marginal cost of producing it. From the consumer's perspective, the gradient of the HPS with respect to local environmental quality gives the equilibrium differential that compensates consumers for accepting the increased health risk and aesthetic disamenities associated with lower local environmental quality. Put another way, areas with poor environmental quality must have lower housing prices to attract potential homeowners, and the HPS reveals the price that allocates consumers across locations. Thus, the HPS can be used to infer the welfare effects of a marginal change in a characteristic. From the suppliers' perspective, the gradient of the HPS reveals the costs of supplying a cleaner local environment.

B. What are the Consequences of a Large Change in Environmental Quality in the Hedonic Model?

This study assesses the impacts of Superfund remediations of hazardous waste sites, which intend to cause non-marginal improvements in environmental quality near the site. This subsection extends and fleshes out the hedonic model to describe the theoretical impacts of these clean-ups on consumers, suppliers, and social welfare. Any impacts on the labor market are ignored, because wage changes don't affect welfare since any gains (losses) for workers are offset by losses (gains) for firms (Roback 1982).

The Impacts of an Amenity Improvement on Consumers and Suppliers. We focus on the case where the overall HPS does not shift in response to the increased supply of "clean" sites. The assumption of a constant HPS may be valid because to date only 670 Superfund sites have been completely remediated. They are located in just 624 of the 65,443 US census tracts, which constitutes a small part of

the US housing market.

Now, consider the clean-up of a hazardous waste site that increases local environmental quality from c_j^1 to c_j^3 as in Figure 1a in the neighborhood surrounding the site. It is evident from the HPS that the rental price of housing near the improved site will rise to p_3. For type #1 consumers, the increase in the rental rate exceeds their willingness to pay for the clean-up. Consequently, their neighborhood has become too expensive, given their preferences and income, and the clean-up reduces their utility.

The result is that consumers will migrate between communities to restore the equilibrium. The type #1 consumers that had chosen the improved site based on its previous rental price and environmental quality will move to a house with their originally chosen and optimal values of p and c_j (i.e., p_1 and c_j^1). Additionally, some type #3 consumers will move near the newly cleaned-up site, where they will consume c_j^3 at a price of p_3. So assuming zero moving costs[10], the key result is that some consumers will change locations, but their utility is unchanged because they choose locations with their original c_j and p.

One consequence of this taste-based sorting is that the residents of the improved neighborhood will have greater unobserved taste for environmental quality and/or higher incomes.[11] Thus, the marginal resident will be less tolerant of exposure to hazardous waste. We test for this taste-based sorting below.

In this set-up, land owners near the site are the only agents whose welfare is affected by the clean-up. If residential and commercial land markets are perfectly integrated, then the higher rental rates are a pure benefit for all landowners because the change in environmental quality is costless for them. In this case, the supply of land for residential purposes is fixed.

It is possible that the residential and non-residential land markets are not perfectly integrated, perhaps due to zoning laws, which are costly to change (Glaeser and Gyourko 2003). In this case, the increase in rental prices is still a pure benefit for owners of residential land near the site. The higher rents

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[10] For simplicity, we assume zero moving costs although this surely isn't correct. In the presence of moving costs, renters are made worse off by the amount of the moving costs. See Bayer, Keohane, and Timmins (2006) on the impacts of moving costs on the valuation of air pollution.

[11] See Banzhaf and Walsh (2005) and Cameron and McConnaha (2005) for evidence of migration induced by environmental changes. In principle, the new residents' incomes could have a direct effect on individuals' valuations of living in the community. We ignore this possibility here because this will not create any social benefits as long as the benefits from living near high income individuals are sufficiently linear.

for residential land will cause some owners of non-residential land to find it profitable to convert their land to residential usage. Presumably, the pre-clean-up rental rate of the converted land had been higher when in the non-residential sector and/or there may be costs associated with conversion (e.g., legal fees associated with rezoning), so the benefits for owners of converted land are smaller than for owners of land that was already used for residential housing. Ultimately, the benefits of conversion determine the shape of the supply curve of residential land near the site and the welfare gain for these land owners. The empirical analysis tests for supply responses.

To summarize, there are four predicted impacts of an amenity improvement. First, the price of land (and housing) near the improved site will increase. Second, consumers will respond with taste-based sorting. Third, the supply of residential land (and housing) near the site is likely to increase. Fourth, the entire welfare gain accrues to land owners. We discuss how to test these predictions with decennial Census data after we develop a formal expression for the welfare effects of a Superfund clean-up.

A General Expression for the Full Welfare Effects. The full welfare benefits are the sum of all consumers' and suppliers' willingness to pay (WTP) for the change in local environmental quality. In contrast to the preceding discussion, here we allow for the possibility that the remediation alters relative prices so that local environmental quality is less expensive. A change in relative prices could affect all consumers and suppliers. Consequently, it is now necessary to account for the WTP of agents living near the improved sites and elsewhere.[12]

The benefits for consumers can be expressed as:

$$\text{(5a)}\ \Delta \text{ Total Consumer WTP} = \sum_i [B_i(c_{ij}^{*post}, \mathbf{C}_{-ij}^{*}, u_i^{*}) - B_i(c_{ij}^{*pre}, \mathbf{C}_{-ij}^{*}, u_i^{*})] - \sum_i [P_i^{post}(c_{ij}^{*post}, \mathbf{C}_{-ij}^{*}) - P_i^{pre}(c_{ij}^{*pre}, \mathbf{C}_{-ij}^{*})],$$

where i indexes a household and there are n households (i=1,..., n) in the country. "Pre" is before the clean-up and "post" is after it and all adjustments are complete.[13] Thus, each consumer's WTP is equal to the difference in her valuation of exposure to c_{ij}^{*post} and c_{ij}^{*pre} minus the difference in the rental rates at

[12] See Bartik (1988) and Freeman (2003) for more extensive discussions of the general welfare impacts of non-marginal amenity improvements.

[13] For simplicity, we assume that consumers do not adjust their consumption of the other characteristics so $\mathbf{C}_{-ij}^{*Pre} = \mathbf{C}_{-ij}^{*Pre}$). We make the analogous assumption about suppliers.

these values of c_{ij}.

The benefits for suppliers can be expressed as:

(5b) Δ Total Supplier WTP = $\sum_k [P_k^{post}(c_{kj}^{*post}, \mathbf{C}_{-kj}^*) - P_k^{pre}(c_{kj}^{*pre}, \mathbf{C}_{-kj}^*)]$
$- \sum_k [\tau_k(c_{kj}^{*post}, \mathbf{C}_{-kj}^*) - \tau_k(c_{kj}^{*pre}, \mathbf{C}_{-kj}^*)]$,

where k indexes a supplier and there are m (k= 1,..., m) suppliers in the country. $\tau_k(\mathbf{C})$ is supplier k's cost of producing a house with characteristics **C**. So each supplier's WTP is equal to the pre and post difference in price minus the difference in costs.

Thus, the societal change in welfare is the sum of equations (5a) and (5b). The price change is a transfer from buyers to sellers so it cancels out. Consequently, the total change in welfare equals the difference in consumers' total willingness to pay at the new and old levels of environmental quality minus the change in suppliers' costs. The implementation of this approach requires reliable estimates of all consumers' bid functions and all suppliers' cost functions.

Three decades after the publication of the original Rosen article, this hedonic approach to estimating the value of amenity changes has not met with great empirical success for at least two reasons. First, the estimation of even a single individual's/taste type's bid function has proven to be extremely challenging, because it is impossible to observe the same individual facing two sets of prices in a cross-section.[14] The difficulty of this task was first underscored by Epple (1987) and Bartik (1987) who showed that taste-based sorting undermines efforts to infer consumers' bid functions from the HPS.[15] Second, the implementation of this approach requires estimates of bid functions for <u>all</u> consumers and cost functions for <u>all</u> suppliers in the economy. This is a tremendous amount of information, and there is a consensus that existing data sources are not up to the task.

C. Can We Learn about the Welfare Effects of Superfund Clean-ups from Decennial Census Data?

This subsection considers how decennial census data on housing and demographic variables can

[14] Rosen (1974) proposed a 2-step approach for estimating bid functions (and offer curves). He later wrote, "It is clear that nothing can be learned about the structure of preferences in a single cross-section" (Rosen 1986, p. 658).

[15] In a recent paper, Ekeland, Heckman and Nesheim (2004) outline the assumptions necessary to identify the demand (and supply) functions in an additive version of the hedonic model with data from a single market.

be used to learn about the welfare effects of Superfund clean-ups. There are at least two features of these data that merit noting because they affect the form and interpretation of the subsequent empirical analysis.

The first feature is that census tracts are the smallest unit of observation that can be matched across the 1980, 1990, and 2000 censuses. This means that it is infeasible to observe individuals over time and therefore to obtain estimates of their bid and cost functions. Consequently, we now consider the impacts of a clean-up in the context of census tract-level demand and supply functions for residential land, which are determined by the bid and cost functions of local consumers and suppliers.

We begin with the case where the supply curve for residential land near a hazardous waste site is perfectly inelastic, which is likely to be the case in the short-run, and demand is downward sloping. This is depicted in Figure 1b with S^1 and D^1 and equilibrium outcome (P_1, Q_1). Now, consider an exogenous increase in environmental quality due to a clean-up. The improvement raises current residents' valuation of living near the formerly dirty site and, as sketched out in the previous subsection, with free migration individuals with even higher valuations of environmental quality will move in. The net result is that the demand curve for residential housing near the improved site shifts out. This is depicted as D^2 and causes prices to increase to P_2 but leaves quantities unchanged.

With a parallel shift in the demand curve and no change in the HPS, the welfare gain is the sum of the shaded areas A_1 and A_2 in Figure 1b. This equals the mean change in price times the number of residential plots of land and entirely accrues to suppliers or landowners. From a practical perspective, the challenge is to accurately measure the change in house or residential land prices near the improved site.

In the longer run, supply is likely to be more elastic due to the conversion of non-residential land, and the remediation will lead to changes in prices <u>and</u> quantities. Figure 1b depicts the unrealistic polar case where supply is perfectly elastic as S_2. With this supply curve, the new equilibrium combination is (P_1, Q_2), which reflects a substantial gain in quantities but no change in prices. The gain in welfare is entirely an increase in consumer surplus and is the sum of the shaded areas B_1, B_2, and A_2. Previous applications of the hedonic method have generally examined prices only, so they may have understated (potentially dramatically) the welfare gain associated with amenity improvements.

It is evident that with census-tract data the development of a full welfare measure requires

knowledge of the shapes of the supply and demand curves. We are unaware of a credible strategy for separately identifying supply and demand over the 10 year periods between censuses. In this situation, precise welfare calculations require ad hoc assumptions about the elasticities of supply and demand, except for the case where neither prices nor quantities change. In fact, the subsequent analysis finds small changes in prices and quantities, so our primary conclusion is that Superfund remediations did not substantially increase social welfare.

The census tract-level demographic data can also be used to test the theoretical prediction of taste-based sorting in response to remediations. An increase in the number of high income individuals or people that are likely to place a high value on environmental quality in areas near the remediated sites would provide complementary evidence that the clean-ups are valued. In contrast, a failure to find these population shifts near the sites would suggest that the clean-ups did not lead to substantial welfare gains.

The second feature of the data that merits highlighting is that they are only available in 1980, 1990, and 2000. Ideally, we would like to measure the impact of a site's placement on the NPL immediately after the announcement so any benefits are in the future and homeowners will naturally discount them by the rate of time preference. An immediate measurement of the impact on prices would ensure that we have captured the impact of the clean-up on the value of housing services in all years. However, the first NPL was released in 1983, and housing prices cannot be observed again until 1990 or 2000. By then, some of the clean-ups will have been completed, and the time to completion for the others (relative to 1983) will have been greatly reduced. For this reason, the measurement of the impacts of the NPL designation with 1990 or 2000 Census data will overstate the properly measured benefits.

III. Data Sources and Summary Statistics

A. Data Sources

We constructed the most comprehensive data file ever compiled on the Superfund program. It contains detailed information on all hazardous waste sites placed on the NPL by 2000, as well as the hazardous waste sites with 1982 HRS scores below 28.5. We also compiled housing price, housing characteristic, and neighborhood demographic information for areas surrounding these sites. This

subsection describes the data sources. More details are provided in the Data Appendix and Greenstone and Gallagher (2005).

The housing, demographic and economic data come from Geolytics's *Neighborhood Change Database*, which includes information from the 1970, 1980, 1990, and 2000 Censuses. Importantly, the 1980 data predate the publication of the first NPL in 1983. We collected the longitude and latitude for each of the hazardous waste sites and used this information to place all sites in a unique census tract.

We use the Geolytics data to form a panel of census tracts based on 2000 census tract boundaries, which are drawn so that they include approximately 4,000 people in 2000. Census tracts are the smallest geographic unit that can be matched across the 1970-2000 Censuses. The Census Bureau placed the entire country in tracts in 2000. Geolytics fit 1970, 1980, and 1990 census tract data to the year 2000 census tract boundaries to form a panel. The primary limitation of this approach is that in 1970 and 1980, the US Census Bureau only tracted areas that were considered 'urban' or belonged to a metropolitan area. The result is that the remaining areas of the country cannot be matched to a 2000 census tract, so the 1970 and 1980 values of the Census variables are missing for 2000 tracts that include these areas.

The analysis is restricted to the 48,147 out of the 65,443 2000 census tracts that have non-missing housing price data in 1980, 1990, and 2000. This sample includes 985 of the 1,398 sites listed on the NPL before January 1, 2000 and 487 of the 690 sites which were tested for inclusion on the initial NPL. The addition of the sample restriction that 1970 housing prices be nonmissing would have further reduced the sample to include just 37,519 census tracts, 708 of the NPL sites, and 353 of the 1982 HRS sites.

The subsequent analysis uses three different groupings of census tracts. The first conducts the analysis at the census tract level. The second implements an analysis among census tracts that share a border with the tracts that contain the hazardous waste sites (but excludes the tracts that contain the sites). In this case, each observation is comprised of the weighted average of all variables across these neighboring tracts, where the weights are the 1980 populations of the tracts.

The unit of observation in the third grouping is the land area within circles of varying radii that are centered at the sites. For these observations, the census variables are calculated as the weighted means across the portion of tracts that fall within the relevant circle. The weights are the fraction of each

tract's land area within the relevant circle multiplied by its 1980 population.[16] In choosing the optimal radius, we attempted to balance the conflicting goals of requiring houses to be near enough to the sites so that it is plausible that residents would value a clean-up and making the area large enough so that implausibly large increases in housing prices aren't required for clean-ups to pass a cost-benefit test. In the subsequent tables, we focus on circles with radii of 2-miles and 3-miles.[17] The mean 1980 values of the housing stocks in these circles are $349 and $796 million and the mean (median) number of census tracts that are at least partially inside these circles are 9.9 (8) and 18.2 (12), respectively.

We also collected a number of variables about the hazardous waste sites. All HRS composite scores, as well as separate groundwater, surface water, and air pathway scores, were obtained from various issues of the *Federal Register*. The same source was used to determine the dates of NPL listing. The EPA provided a data file that reported the dates of the release of the ROD, initiation of clean-up, completion of remediation (i.e., construction complete), and deletion from the NPL for sites that achieved these milestones. Information on each NPL site's size in acres comes from the RODs. Finally, we collected data on the expected costs of clean-up before remediation was initiated and estimated actual costs for sites that reached the construction complete stage. Greenstone and Gallagher's (2005) Data Appendix provides more information on the costs of clean-ups (also see Probst and Konisky 2001).

B. Summary Statistics

The analysis is conducted with two samples of hazardous waste sites. The first is called the "All NPL Sample" and includes the 1,398 hazardous waste sites in the 50 US states and the District of Columbia that were placed on the NPL by January 1, 2000. The second is the "1982 HRS Sample" and is comprised of the 690 hazardous waste sites tested for inclusion on the initial NPL.

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[16] A limitation of the GIS determined circle approach is that street address level data on housing prices and the covariates is unavailable. We assign a census tract's average to the portion of the tract that falls within the circle, which is equivalent to assuming that there is no heterogeneity in housing prices or other variables within a tract.

[17] Our use of a 3-mile radius is consistent with the EPA's and scientific community's positions on the distance from a Superfund site that the contaminants could be expected to impact human health. The 1982 Federal Register reports, "The three-mile radius used in the HRS is based on EPA's experience that, in most cases currently under investigation, contaminants can migrant to at least this distance. It should be noted that no commentators disagreed with the selection of three miles for technical or scientific reasons" (Federal Register July 16, 1982).

Table 1 presents summary statistics on the hazardous waste sites in these samples. The entries in column (1) are from the All NPL Sample and are limited to sites in a census tract for which there is non-missing housing price data in 1980, 1990, and 2000. After these sample restrictions, there are 985 sites, which is more than 70% of the sites placed on the NPL by 2000. Columns (2) and (3) report data from the 1982 HRS Sample. The column (2) entries are based on the 487 sites located in a census tract with complete housing price data. Column (3) reports on the remaining 189 sites located in census tracts with incomplete housing price data (generally due to missing 1980 data). 14 sites are outside of the continental United States and were dropped from the sample.

Panel A reports on the timing of the sites' placement on the NPL. Column (1) reveals that about 75% of all NPL sites received this designation in the 1980s. Together, columns (2) and (3) demonstrate that 443 of the 676 sites in the 1982 HRS Sample eventually were placed on the NPL. This number exceeds the 400 sites that Congress set as an explicit goal, because, as we have discussed, some sites with initial scores below 28.5 were rescored and then received scores above the threshold qualifying them for the NPL. Panel B demonstrates that mean HRS scores are similar across the columns.

Panel C reports on the size of the hazardous waste sites measured in acres, which is available for NPL sites only. The median site size ranges between 25 and 35 acres across the samples. The means are substantially larger due to a few very large sites. The modest size of most sites suggests that any expected effects on property values are likely to be confined to relatively small geographic areas around the sites.

Panel D reveals that the clean-up process is slow. The median time until the different milestones are achieved is reported, rather than the mean, because many sites have not reached all of the milestones yet. 198 (16) of the NPL sites in column (2) received either the construction complete or deleted designation by 2000 (1990). For this reason, we focus on changes in housing prices and quantities between 1980 and 2000. We will also assess how rental rates change as sites move through the different stages of the clean-up process.

Panel E reports the expected costs of clean-up for NPL sites, and F details expected and actual costs among sites that are construction complete or deleted. The expected costs are measured before any remediation activities have begun, while actual costs are our best estimates of total remediation related

expenditures assessed after the site is construction complete. We believe this is the first time these variables have been reported for the same sites. In the 1982 HRS Sample that we focus on (i.e., column (2)), the mean and median expected costs are \$27.5 million and \$15.0 million.

Among the construction complete sites in the 1982 HRS Sample, the mean actual costs exceed the expected costs by about 55%. We multiply the overall mean expected cost of \$27.5 million by 1.55 to obtain an estimate of the mean actual costs of clean-up in the 1982 HRS Sample of \$43 million. This estimate of costs understates the true costs, because it does not include the legal costs or deadweight loss associated with the collection of funds from private parties or taxes, nor does it include the site's share of the EPA's costs of administering Superfund. Nevertheless, it is contrasted with the estimated benefits of Superfund clean-ups in the remainder of the paper.

A comparison of columns (2) and (3) across the panels reveals that the sites with and without complete housing price data are similar on a number of dimensions. For example, the mean HRS scores conditional on scoring above and below 28.5 are remarkably similar. Further, the median size and various cost variables are comparable in the two columns. Consequently, it seems reasonable to conclude that the sites without complete housing price data are similar to the column (2) sites, suggesting the subsequent results may be representative for the entire 1982 HRS Sample.

Moreover, the sites in column (1) are similar to the sites in column (2) and (3) in size and the two cost variables. The mean HRS scores are a few points lower, but this comparison is not meaningful due to the changes in the test over time and changes in the how the scoring was conducted. Overall, the similarity of the column (1) sites with the other sites suggests that it may be reasonable to assume that the results from the application of the HRS research design to the 1982 HRS Sample are informative about the effects of the other Superfund clean-ups.

We now graphically summarize some other features of the two samples. Figure 2 displays the geographic distribution of the 985 hazardous waste sites with complete housing data in the All NPL Sample. There are NPL sites in 45 of the 48 continental states, demonstrating that Superfund is genuinely a national program. The highest proportion of sites is in the Northeast and Midwest (i.e., the "Rust Belt"), reflecting the historical concentration of heavy industry in these regions.

Figures 3A and 3B present the geographic distribution of the 487 sites with complete house price data in the 1982 HRS Sample. Figure 3A (3B) displays the distribution of sites with 1982 HRS scores exceeding (below) 28.5. The sites in both categories are spread throughout the United States, but the below 28.5 sites are in fewer states. For example, there are not any below 28.5 sites in Minnesota, Florida, and Delaware. The unequal distributions of sites across the country pose a problem for identification in the presence of localized housing market shocks. To mitigate the influence of these shocks, we emphasize econometric models for changes in housing prices that include state fixed effects.

Figure 4 presents a histogram of the initial HRS scores where the bins are 4 HRS points wide, among the 487 sites in the 1982 HRS Sample. Notably, the EPA considered HRS scores within 4 points to be statistically indistinguishable and reflect comparable risks to human health (EPA 1991). The distribution looks approximately normal, with the modal bin covering the 36.5-40.5 range. Further, there isn't obvious bunching just above or below the threshold, which supports the scientific validity of the HRS scores and suggests that they weren't manipulated. Importantly, 227 sites have HRS scores between 16.5 and 40.5. This set is centered on the regulatory threshold of 28.5 that determines placement on the NPL and constitutes the regression discontinuity sample that we exploit in the subsequent analysis.

IV. Econometric Methods

A. Least Squares Estimation with Data from the Entire U.S.

Here, we discuss a conventional econometric approach to estimating the relationship between housing prices and NPL listing. This approach is laid out in the following system of equations:

(6) $y_{c2000} = \theta\, 1(NPL_{c2000}) + X_{c1980}'\beta + \varepsilon_{c2000}$,

(7) $1(NPL_{c2000}) = X_{c1980}'\Pi + \eta_{c2000}$,

where y_{c2000} is the log of the median property value in census tract c in 2000. The indicator variable $1(NPL_{c2000})$ equals 1 only for observations from census tracts that contain (or areas near) a hazardous waste site that has been placed on the NPL by 2000. Thus, this variable takes on a value of 1 for any of the Superfund sites in column (1) of Table 1, not just those that were on the initial NPL. The vector X_{c1980} includes determinants of housing prices measured in 1980, which may also determine NPL

status. ε_{c2000} and η_{c2000} are the unobservable determinants of housing prices and NPL status, respectively.

A few features of the X vector are noteworthy. First, we restrict this vector to 1980 values of the variables to avoid confounding the effect of NPL status with "post-treatment" changes in these variables that may be due to NPL status. Second, we include the 1980 value of the dependent variable, y_{c80} in X_{c1980}, to adjust for permanent differences in housing prices across tracts and the possibility of mean reversion in housing prices. Third, to account for local housing market shocks, we emphasize results from specifications that include a full set of state fixed effects.

Fourth, in many applied hedonic papers, the vector of controls is limited to housing and neighborhood characteristics (e.g., number of bedrooms, school quality, and air quality). Income and other similar variables are generally excluded on the grounds that they are "demand shifters" and are needed to identify the bid function. However, this exclusion restriction is invalid if individuals treat wealthy neighbors as an amenity, which seems likely. In the subsequent analysis, we are agnostic about which variables belong in the X vector and report estimates that are adjusted for different combinations of the variables available in the Census data. The Data Appendix lists the full set of covariates.

The coefficient θ measures the effect of NPL status on 2000 property values, after controlling for 1980 mean property values and the other covariates. Specifically, it tests for differential housing price appreciation between census tracts with NPL sites and the rest of the country. If there are unobserved determinants of housing prices that covary with NPL status, then the estimates of θ will be biased. More formally, consistent estimation requires $E[\varepsilon_{c2000}\eta_{c2000}] = 0$. Ultimately, this "conventional" approach places a lot of faith in the assumption that linear adjustment for the limited set of variables available in the Census removes all sources of confounding.

B. A Quasi-Experimental Approach based on the 1982 HRS Research Design

This subsection discusses our preferred identification strategy that has two key differences with the conventional one. First, we limit the sample to the census tracts containing the 487 sites in the 1982 HRS Sample with complete housing price data. Thus, all observations are from tracts with sites that the EPA judged to be among the nation's most dangerous in 1982. If, for example, the β's differ across tracts

with and without hazardous waste sites or there are differential trends in housing prices in tracts with and without these sites, then this approach is more likely to produce consistent estimates. Second, we use an instrumental variables (IV) strategy to account for the possibility of endogenous rescoring of sites.

More formally, we replace equation (7) with:

(8) $1(NPL_{c2000}) = X_{c1980}'\Pi + \delta\ 1(HRS_{c82} > 28.5) + \eta_{c2000}$,

where $1(HRS_{c82} > 28.5)$ serves as an instrumental variable. This indicator function equals 1 for census tracts with a site that has a 1982 HRS score exceeding the 28.5 threshold. We then substitute the predicted value of $1(NPL_{c2000})$ from the estimation of equation (8) in the fitting of (6) to obtain an estimate of θ_{IV}. In this IV framework, θ_{IV} is identified from the variation in NPL status that is due to a site having a 1982 HRS score exceeding 28.5.

For θ_{IV} to provide a consistent estimate of the HPS gradient, the instrumental variable must affect the probability of NPL listing without having a direct effect on housing prices. The next section will demonstrate that the first condition clearly holds. The second condition requires that the unobserved determinants of 2000 housing prices are orthogonal to the portion of the nonlinear function of the 1982 HRS score that is not explained by X_{c1980}. In the simplest case, the IV estimator is consistent if $E[1(HRS_{c82} > 28.5)\ \varepsilon_{c2000}] = 0$.

We also exploit the regression discontinuity design implicit in the $1(\bullet)$ function that determines NPL eligibility in three separate ways to obtain IV estimates that allow for the possibility that $E[1(HRS_{c82} > 28.5)\ \varepsilon_{c2000}] \neq 0$ over the entire 1982 HRS Sample. In the first, a quadratic in the 1982 HRS score is included in X_{c1980} to partial out any correlation between residual housing prices and the indicator for a 1982 HRS score exceeding 28.5. This approach relies on the plausible assumption that residual determinants of housing price growth do not change discontinuously at the regulatory threshold. The second regression discontinuity approach involves implementing our IV estimator on the regression discontinuity sample of 227 sites with 1982 HRS scores between 16.5 and 40.5. Here, the identifying assumption is that all else is held equal in the "neighborhood" of the regulatory threshold. More formally, it is $E[1(HRS_{c82} > 28.5)\ \varepsilon_{c2000} | 16.5 < 1982\ HRS < 40.5] = 0$.

Recall, the HRS score is a nonlinear function of the ground water, surface water, and air

migration pathway scores. The third regression discontinuity method exploits knowledge of this function by including the individual pathway scores in the vector X_{c1980}. All three regression discontinuity approaches are demanding of the data and this is reflected in higher sampling errors.

V. Empirical Results

A. Balancing of Observable Covariates

This subsection examines the comparisons that underlie the subsequent least squares and quasi-experimental IV estimates of the effect of NPL status on housing price growth. We begin by assessing whether NPL status and the $1(HRS_{c82} > 28.5)$ instrumental variable are orthogonal to the observable predictors of housing prices. Formal tests for the presence of omitted variables bias are of course impossible, but it seems reasonable to presume that research designs that balance the observable covariates across NPL status or $1(HRS_{c82} > 28.5)$ may suffer from smaller omitted variables bias (Altonji, Elder, and Taber 2000). Further, if the observables are balanced, consistent inference does not depend on functional form assumptions on the relations between observable covariates and housing prices.

Table 2 shows the association of NPL status and $1(HRS_{c82} > 28.5)$ with potential determinants of housing price growth measured in 1980. Column (1) reports the means of the variables listed in the row headings in the 985 census tracts with NPL hazardous waste sites and complete housing price data. Column (2) displays the means in the 41,989 census tracts that neither contain a NPL site nor share a border with a tract containing one. Columns (3) and (4) report on the means in the 181 and 306 census tracts with hazardous waste sites with 1982 HRS scores below and above the 28.5 threshold, respectively. Columns (5) and (6) repeat this exercise for the 90 and 137 tracts below and above the regulatory threshold in the regression discontinuity sample. The remaining columns report p-values from tests that the means in pairs of the first six columns are equal. P-values less than 0.01 are denoted in bold.

Column (7) compares the means in columns (1) and (2) to explore the possibility of confounding in the least square approach. The entries indicate that 1980 housing prices are more than 20% lower in tracts with a NPL site. Moreover, the tracts with NPL sites have lower population densities, lower household incomes, and mobile homes account for a higher fraction of the housing stock (8.6% versus

4.7%). Overall, the hypothesis of equal means can be rejected at the 1% level for 21 of the 27 potential determinants of housing prices. Due to this confounding of NPL status, it may be reasonable to assume that least squares estimation of equation (6) will produce biased estimates of the effect of NPL status.

Columns (8) and (9) compare all tracts with hazardous wastes that have 1982 HRS scores below and above the 28.5 regulatory threshold and those in the regression discontinuity sample, respectively. It is immediately evident that by narrowing the focus to these tracts, the differences in the potential determinants of housing prices are greatly mitigated (see especially population density and percentage of mobile homes). This is especially so in the regression discontinuity sample where the hypothesis of equal means cannot be rejected at the 3% level for any of the 27 variables. Notably, the differences in the means are substantially reduced for many of the variables, so the higher p-values do not simply reflect the smaller samples (and larger sampling errors).

One variable that remains a potential source of concern is 1980 housing prices. The differences are greatly reduced in the 1982 HRS Sample, relative to columns (1) and (2), but they are not eliminated. However, Panel B of Table 4 in Greenstone and Gallagher (2005) demonstrates that these differences entirely disappear after adjustment for the 1980 housing, economic, and demographic variables. Nevertheless, we control for 1980 housing prices in the regressions for 2000 housing prices below. Overall, the entries suggest that the above and below 28.5 comparison, especially in the regression discontinuity sample, reduces the confounding of NPL status. It is not a panacea, however, so we also adjust for observables.

B. Least Squares Estimates of the Impact of Clean-ups on Property Values

Table 3 presents the first ever large-scale effort to test the effect of Superfund clean-ups on property value appreciation rates. Specifically, it reports the regression results from fitting 4 least squares versions of equation (6) for 2000 housing prices. In Panel A, 985 observations are from census tracts that contain a hazardous waste site that had been on the NPL at any time prior to 2000.[18] The remainder of the

[18] The 985 NPL sites are located in 892 individual census tracts. In the regressions, observations on tracts that

sample is comprised of the 41,989 observations on the tracts with complete housing price data that neither have a NPL site nor are adjacent to a tract with a NPL site.

The remaining Panels use slightly different samples. In Panel B, the observations from each tract with a NPL site in the Panel A sample are replaced with the observations based on the 3-mile radius circles around the NPL sites. Panels C and D are identical to A and B, except that the set of NPL sites is limited to the hazardous waste sites in the 1982 HRS Sample that were ever on the NPL by January 1, 2000. These last two panels are included so that they can be compared to the subsequent quasi-experimental results.

The entries report the coefficient and heteroskedastic-consistent standard error on the NPL indicator. All specifications control for the natural log of the mean housing price in 1980, so the reported parameter should be interpreted as the growth in housing prices in areas near a NPL site, relative to the rest of the country. The exact covariates in each specification are noted in the row headings at the bottom of the table and are described in more detail in the Data Appendix.

The Panel A results show that this least squares approach finds a positive association between NPL listing and housing price increases in the sites' tracts between 1980 and 2000. Specifically, the estimates in the first row indicate that median housing prices grew by 4.0% to 7.3% (measured in ln points) more in tracts with a site placed on the NPL. All of these estimates would easily be judged statistically significant by conventional criteria. The column (4) estimate of 6.7% is the most reliable one, because it is adjusted for all unobserved state-level determinants of housing price growth.

Panel B explores the growth of housing prices within 3 miles of the NPL sites to summarize the total gain in housing prices. We report p-values from tests that the coefficients on the NPL indicator are large enough so that Superfund clean-ups pass a cost-benefit test based on the assumption that the benefits are entirely reflected in local housing prices. As discussed in Section II, this is equivalent to assuming that there is a perfectly inelastic supply curve. (It also assumes that all program benefits occur in the local housing market.) In this sample, the 1980 aggregate value of the housing stock is $874 million and the

include multiple NPL sites have a weight equal to the square root of the number of sites.

mean cost of a clean-up is \$39 million, so we test whether the change in housing prices exceeds 4.5%.

All of the estimates are statistically different from zero and imply that the placement of a site on the NPL is associated with a substantial increase in housing prices within three miles of the site. The column (4) specification indicates a precisely estimated gain in prices of 10.6%. The null that the clean-ups pass this cost-benefit test cannot be rejected in any of the specifications.

The own census tract results in Panel C are similar to those in A. The 3-mile radius circle results in D indicate large increases in housing prices, like those in Panel B. The point estimates from the richer specifications are about twice as large as those in B, and, if taken literally, all of the estimates also indicate that Superfund passes this cost-benefit test.

Before drawing any definitive conclusions or policy implications, however, it is worth emphasizing that three features of the evidence presented so far suggest that the Table 3 estimates may be unreliable. First, Table 2 demonstrated that NPL status is confounded by many variables. Second, 6 of the 8 3-mile radius sample point estimates exceed the own census tract estimates. This seems suspicious, because it seems reasonable to expect the impact on housing prices to be greater closer to the sites, especially in light of their relatively small size (recall, the median size is less than 30 acres). Third, the point estimates from the 3-mile samples are unstable across specifications, so the exact choice of controls plays a large role in any conclusions. For example, in Panel D, the implied increase in housing prices ranges from 4.6% to 23.2%.[19]

C. Quasi-Experimental Estimates of NPL Status on Housing Prices from the 1982 HRS Sample

We now turn to the preferred quasi-experimental approach and begin by assessing the relationship between 1982 HRS scores and NPL status. Figure 5 plots the bivariate relation between the probability that a site was placed on the NPL by 2000 and its initial HRS score among the 487 sites in the

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[19] It is also noteworthy that the point estimate on the NPL indicator is quite sensitive to the choice of functional form for two controls: the number of housing units and number of owner occupied units in both Panels B and D. This likely reflects the fact that the values of these variables differ substantially between the observations on the 3-mile circles and the census tracts. It also underscores the importance of unverifiable functional form assumptions when the variables are not balanced across the areas with and without NPL sites.

1982 HRS Sample. The plots are done separately for sites above and below the 28.5 threshold and come from the estimation of nonparametric regressions that use Cleveland's (1979) tricube weighting function and a bandwidth of 0.5.[20] Thus, they represent a moving average of the probability of NPL status across 1982 HRS scores. The data points represent the mean probabilities in the same 4-unit intervals of the HRS score as in Figure 4.

The figure presents dramatic evidence that an initial HRS score above 28.5 is a strong predictor of NPL status. Virtually all sites with initial scores greater than 28.5 were placed on the NPL by 2000. Again, rescoring explains the nonzero probability of placement on the NPL by 2000 among sites with an initial score below 28.5. A statistical version of the figure reveals that a HRS score above 28.5 is associated with an 83% increase in the probability of placement on the NPL (Greenstone and Gallagher 2005). It is evident that there is a powerful first-stage relationship

Table 4 presents IV estimates of the effect of NPL status on housing prices in 2000. In Panel A, the observations are from the census tracts containing the 487 hazardous waste sites in the 1982 HRS Sample. In Panel B, each observation is comprised of the average of all variables across tracts that share a border with these tracts. In Panels C and D, the sample is comprised of the land area within circles with radii of 2 and 3 miles that are centered at each site's longitude and latitude. The means of the 1980 values of the total housing stock in the four samples are \$71, \$525, \$349, and \$796 million, respectively.

The controls in the first four columns are identical to those in the four specifications in Table 3. In the fifth column, the 1982 HRS score and its square are added to the column (4) specification. In column (6), the controls are the same as in column (4), but the sample is the regression discontinuity sample that is comprised of the 227 sites with 1982 HRS scores between 16.5 and 40.5. The sample and specification details are noted in the row headings at the bottom of the table.

The Panel A results suggest that a site's placement on the NPL has little impact on the growth of property values in its own census tract, relative to tracts with sites that narrowly missed placement on the

[20] The smoothed scatterplots are qualitatively similar with a rectangular weighting function (i.e., equal weighting) and alternative bandwidths.

NPL. The point estimates indicate an increase in prices that ranges from 0.7% to 5.6%, but they all have associated t-statistics less than two. The regression discontinuity specifications in columns (5) and (6) may be the most credible, so it is notable that they produce the smallest point estimates (although they are also the least precise).

Panel B presents the adjacent tract results. The point estimates from the most reliable specifications in columns (4) – (6) range between -0.6% and 1.5% and zero cannot be rejected at conventional levels for any of them. Thus, there is little evidence of meaningful gains in housing prices outside the site's own census tract.

Panels C and D summarize the total gain in housing prices associated with a site's placement on the NPL by using the 2- and 3-mile radius circle samples. They also report whether the clean-ups pass cost-benefit tests analogous to those in Table 3. The threshold housing price gains are 12.3% and 5.4%.

The circle sample results provide further evidence that the NPL designation has little effect on housing prices. In the columns (4) – (6) specifications, the point estimates all imply price increases smaller than 2%. Further in all six of the 2-mile specifications and the most reliable 3-mile ones, the null that the gain in housing prices exceeds the break-even threshold is rejected at conventional significance levels. Overall, these quasi-experimental estimates suggest that Superfund clean-ups fail to pass this cost-benefit test. This finding further undermines the credibility of the results from the conventional approach that suggested that the benefits substantially exceeded the costs.

Figure 6 provides an opportunity to better understand the source of these regression results. It plots the nonparametric regressions of 2000 residual housing prices (after adjustment for the column (4) covariates) against the 1982 HRS score in the 2-mile radius sample.[21] The nonparametric regression is estimated separately below (dark line) and above (light line) the 28.5 threshold. The graph confirms that there is little association between 2000 residual housing prices and the 1982 HRS score. A comparison of

[21] Figure 6 provides a qualitative graphical exploration of the regression results. The relationship between housing prices and 1982 HRS scores cannot be exactly inferred from this graph, because the HRS score has not been adjusted for the column (4) covariates. This same caveat applies to Figure 7. However, the meaningfulness of this graph is supported by Table 2's finding that the covariates are well balanced among sites with 1982 HRS scores above and below the regulatory threshold, especially near the regulatory threshold.

the plots at the regulatory threshold is of especial interest in light of the large jump in the probability of placement on the NPL there. It is apparent that the moving averages from the left and right are virtually equal at the threshold.

Table 5 presents the results from a series of specification checks, all of which are fit on the 2-mile radius circle sample. For conciseness, we only present estimates from the column (1) specification and the three most robust specifications (i.e., columns 4, 5, and 6) from Table 4.

Panel A reports the results from the third regression discontinuity style approach, which adds the individual pathway scores to the vector X_{c1980} of controls in all four specifications. Panel B adds the 2000 values of the controls as separate covariates. These variables may be affected by the clean-ups so they may be endogenous. To isolate the effect of NPL status on land values (rather than housing values), however, it may be appropriate to adjust for these variables. In Panel C, the dependent variable is the ln of the 1990 (rather than 2000) median house value and NPL status is also measured as of 1990. Taken together, these specifications provide further support for the Table 4 finding that the NPL designation has little effect on the growth of property values.

Panel D tests whether the effect of the NPL designation differs in the 2-mile circles with a population density exceeding 4,053 per square mile, which is the top quartile among tracts in this sample.[22] The intuition is that the price response to clean-ups may be greater in higher density areas where there are fewer undeveloped plots of land to build new houses.[23] Specifically, the specification now includes an indicator for these tracts and the additional variable of interest, which is the interaction of this indicator and the indicator for 2000 NPL status. The latter variable is treated as endogenous and instrumented with the interaction of indicators for tract population density exceeding 4,053 and sites with a HRS score exceeding 28.5. All of the estimates of the interaction are negative, and none would be judged to be statistically different from zero. It seems that the absence of a price effect is not due to an abundance of undeveloped plots of land, although we directly estimate supply responses below.

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[22] Of the sites in the 122 tracts with a population density exceeding 4,053, 63 have a HRS score exceeding 28.5 and 70 have sites placed on the NPL by 2000.

[23] Notably, Davis (2004) finds a 13% house price response to the outbreak of a cancer cluster in Churchill County, Nevada, which has a population density of just 5 people per square mile.

We conducted a number of other specification checks. These included using the ln of the mean (rather than the median) house price as the dependent variable, using a fixed effects style approach where the difference between the lns of 2000 and 1980 house prices is the dependent variable (rather than controlling for 1980 ln prices), controlling for the fraction of census tracts within the 2-mile circles with a boundary change between 1980 and 2000, and adding the 1970 values of the controls (including the ln of 1970 housing prices) as separate covariates to adjust for mean reversion or pre-existing trends in the subsample where these variable are available. These specification checks all lead to the same qualitative finding that a site's addition to the NPL has little effect on the growth of nearby housing prices nearly 20 years later.[24] [25]

D. Quasi-Experimental Estimates of Stages of Superfund Clean-Ups on Rental Rates

We now turn to using the ln median rental rates as the outcome variable. Rental units account for roughly 20% of all housing units and generally differ on observable characteristics from owner occupied homes. This outcome's appeal is that rental rates are a measure of the current value of housing services, so it is possible to abstract from the problem with the housing price outcome that individuals' expectations about time until the completion of the clean-up are unknown. Further, we can test whether the impact on the value of local housing services varies at different stages of Superfund clean-ups.

Table 6 presents separate estimates of the effect of the different stages of the remediation process on the ln median rental rate. We stack equations for 1990 and 2000 ln rental rates, so there are two observations per county. The 1980 housing characteristics variables are calculated across rental units,

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[24] The own census tract sample regression results for some of these specification checks are presented in Greenstone and Gallagher (2005). That version of the paper also reports on a test of whether there was greater housing price appreciation near sites where the groundwater was heavily contaminated and residents use well water for drinking. We assumed that clean-ups would be highly valued in these areas, however this test also failed to find significant evidence of differential house price appreciation in these areas (see Greenstone and Gallagher 2005). Additionally, we would have liked to test whether the effects of clean-ups differed for large sites or ones where the estimated costs of clean-up are high (so called "mega" sites) but the size and estimated cost data are only available for NPL sites.

[25] Probst and Konisky (2001) find that approximately 14.5% of RODs ultimately receive a "no further action" classification when removal activities were sufficient to remove the environmental risk and/or the risk naturally dissipated. There are eleven sites in the 1982 HRS Sample where all RODs received the "no further action" classification so no remediation activities took place at them. The regression results are virtually identical to those presented in Table 4 when the observations from near these sites are dropped.

rather than across owner occupied units as in the above analysis of housing prices. The effects of all of the controls listed in the row headings are allowed to differ in 1990 and 2000.

The indicator variable for NPL status is replaced by three independent indicator variables. They are equal to 1 for sites that by 1990 or 2000 were: placed on the NPL but no ROD had been issued; issued a ROD but were not completely remediated; and "construction complete" or deleted from the NPL, respectively. The instruments are the interactions of the indicator for a 1982 HRS score above 28.5 and these three independent indicators. The table reports the point estimates and their standard errors, which allow for clustering at the site level, along with the p-value from an F-test that the three point estimates are equal. The number of sites in each category and the mean HRS score is also listed in brackets.

There is some evidence that higher voter turnout and per capita income are associated with the speed through which a site moves through the clean-up process and the stringency of clean-ups (Gupta et al., 1995 and 1996; Viscusi and Hamilton 1999; Sigman 2001). Consequently, the two stage least squares strategy is unlikely to purge these sources of endogeneity, so it is appropriate to consider these three parameter estimates associational or descriptive.

There are a few important findings. First, sites in the "NPL Only" category have been on the NPL for either 7 or 17 years, but the EPA has not developed a remediation plan for them yet. The estimates from the more reliable specifications suggest that there is little effect on rental rates near these sites. This finding undermines a key feature of the popular "stigma" hypothesis that a site's placement on the NPL leads to an immediate reduction in the value of housing services near the site as nearby residents revise upwards their expectation of the risk they face from the site.[26] Second, in the more reliable specifications, the point estimates for the "Construction Complete or NPL Deletion" category are all negative, and zero cannot be rejected for any of them. This finding is telling, because these sites have been fully remediated and yet there is little effect on rental rates.

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[26] The stigma hypothesis states that a site's placement on the NPL causes nearby residents to revise their expectation of a site's health risk upwards permanently so that the value of nearby housing services declines relative to before its listing on the NPL, even after remediation is completed. Harris (1999) reviews the stigma literature and McCluskey and Rausser (2003) and Messer, Schulze, Hackett, Cameron, and McClelland (2004) are case studies that present evidence that prices decline immediately after the announcement that a local site has been placed on the NPL.

Third, the null that the three parameter estimates are equal cannot be rejected in any of the specifications. This result demonstrates that the approximately zero effect on housing prices is not due to the averaging of a positive effect at fully remediated sites and a negative effect at sites where remediation is incomplete or hasn't been initiated. Overall, these results are consistent with the housing price findings that Superfund clean-ups have small effects on the value of local housing services.

E. Quasi-Experimental Estimates of the Effect of NPL Status on Demand Shifters

If consumers value Superfund clean-ups, then the clean-ups should lead to migration, so that by 2000 the population near NPL sites is comprised of individuals that place a higher value on environmental quality. Table 7 tests whether there were changes in the income and wealth (i.e., education) of residents, demand shifters measured by demographic characteristic of residents, and total population near NPL sites, respectively. The entries report the parameter estimate and standard error on the dummy for NPL status from four specifications. The row headings provide specification details.

The estimated impacts of the NPL designation on the measures of income and wealth are inconsistent across specifications and imprecisely estimated. We had hypothesized that families with children would be more willing to live in these areas after the clean-ups. However, Panel B fails to provide any meaningful evidence that the NPL designation leads to changes in the demographic demand shifter (and racial justice) outcomes. Finally, the instability of the point estimates across specifications in Panel C suggests that there is little effect on total population.

Notably, this table's qualitative findings are unchanged by the inclusion of 1980 housing prices and housing characteristics as covariates. Overall, there is little evidence that the NPL designation is associated with changes in variables that proxy for shifts in demand for environmental quality.

F. Quasi-Experimental Estimates of the Effect of NPL Status on Supply

An increase in the supply of housing units in the vicinity of a NPL site would provide evidence that Superfund clean-ups increase the value of the surrounding land. In Table 8, we test this possibility with the 2- and 3-mile radius samples, using the same four specifications from Tables 5 and 6. These

results are also inconsistent across specifications. The most reasonable conclusion is that the assignment of the NPL designation has little effect on the supply of housing. Figure 7 plots nonparametric regressions of 2000 residual housing units after adjustment for the column (2) covariates from the 2 mile radius sample. There is little evidence of an increase in housing units near sites with initial HRS scores that exceed 28.5, especially at the regulatory threshold.

VI. Interpretation and Policy Implications

This paper has shown that across a wide range of housing market outcomes, there is little evidence that Superfund clean-ups increase social welfare substantially. In light of the significant resources devoted to these clean-ups and the claims of large health benefits, this finding is surprising. This section reviews three possible explanations.

First, the individuals that choose to live near these sites before and after the clean-ups may have a low willingness to pay to avoid exposure to hazardous waste sites. In this case, society provides these individuals a good that they don't value highly. It is possible (and perhaps likely) that there are segments of the population with a high WTP to avoid exposure to hazardous waste sites. It may even be the case that the population average WTP is substantial. However, the policy relevant parameter is the WTP of the population that lives near these sites, and this is the parameter that the paper has estimated.[27]

Second, scientific has not found decisive evidence of substantial health benefits from the clean-ups of hazardous waste sites (Vrijheid 2000; Currie, Greenstone and Moretti 2006). Consequently, consumers believe that the reductions in risk are small and rationally place a low value on them. Of course, the discovery of large health improvements in the future could cause consumers to increase their valuations of the clean-ups.[28]

Third, the sites with initial HRS scores less than 28.5 also received complete remediations under

[27] A popular theory is that sites become permanently stigmatized when they are placed on the NPL. Recall, the rental rate results in Section V D are inconsistent with this theory and would lead to a rejection of this hypothesis.
[28] Another possibility is that consumers are imperfectly informed about the location of Superfund sites and their clean-ups. We think this is unlikely, because local media often devote extensive coverage to local Superfund sites and their clean-ups. Further, at least a few states (e.g., Alaska and Arizona) require home sellers to disclose whether there are hazardous waste sites in close proximity.

state or local land reclamation programs. In this case, a zero result is to be expected since both the above and below 28.5 sites would have received the same treatment. We investigated this possibility by conducting an extensive search for information on remediation activities at these sites.[29]

From these investigations, we concluded that the clean-up activities were dramatically more ambitious and costly at sites with initial scores exceeding 28.5. For example, we were unable to find evidence of any remediation activities by 2000 at roughly 60% of the sites with scores below 28.5. Further, among the 40% of the sites where there was evidence of clean-up efforts, the average expenditure was roughly \$3 million. This is about \$40 million less than our estimate of the average cost of a Superfund clean-up. This difference is not surprising, because the state and local clean-ups were often limited to restricting access to the site or containing the toxics, rather than trying to achieve Superfund's goal of returning the site to its "natural state." Nevertheless, some remediation took place at these sites, so it may be appropriate to interpret the results as the impact of the extra \$40 million that a Superfund clean-up costs.

In our view, the most likely explanations are that the people that choose to live near these sites don't value the clean-ups or that consumers have little reason to believe that the clean-ups substantially reduce health risks. In either case the results mean that given the current state of knowledge, local residents' gain in welfare from Superfund clean-ups falls well short of the costs. The implication is that less ambitious operations like the erection of fences, posting of warning signs around the sites, and simple containment of toxics might be a more efficient use of resources.

This paper has provided an important piece of what would constitute a full accounting of Superfund's benefits. It is possible that there are other benefits of these clean-ups that are not captured in the local housing market, including health and aesthetic benefits to individuals that do not live in close proximity to Superfund sites, reductions in injuries to ecological systems, and protection of ground water.

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[29] Specifically, we filed freedom of information act requests with the EPA for information on these sites and followed any leads from these documents. We also searched the Superfund web site and the sites of state departments of environmental quality and used internet search engines. Additionally, we contacted national and regional EPA personnel and state and local environmental officials. Although we expended considerable effort in these searches, there is no centralized database about these sites so we cannot be certain that further efforts wouldn't turn up different information.

Further, the discovery of compelling evidence of health benefits might cause local residents to increase their valuations, and this would presumably be reflected in the housing market.

VII. Conclusions

This study has used the housing market to develop estimates of the local welfare impacts of Superfund sponsored clean-ups of hazardous waste sites. The basis of the analysis is a comparison of housing market outcomes in the areas surrounding the first 400 hazardous waste sites chosen for Superfund clean-ups to the areas surrounding the 290 sites that narrowly missed qualifying for these clean-ups. We find that Superfund clean-ups are associated with economically small and statistically indistinguishable from zero local changes in residential property values, property rental rates, housing supply, total population, and the types of individuals living near the sites. These findings are robust to a series of specification checks, including the application of a quasi-experimental regression discontinuity design based on knowledge of the selection rule. Overall, the preferred estimates suggest that the local benefits of Superfund clean-ups are small and appear to be substantially lower than the $43 million mean cost of Superfund clean-ups.

More broadly, this paper makes two contributions. First, it models the consequences of a quasi-experiment that improves a local amenity in the context of the hedonic model. The key theoretical findings are that if consumers value the amenity, then there will be increases in local housing prices and new home construction. Further, there will be taste-based sorting such that individuals that place a high value on the amenity will move to areas where they can consume it. Second, it contributes to a growing body of research (Black 1999; Chay and Greenstone 2005) demonstrating that it is possible to identify research designs that mitigate the confounding that has historically undermined the credibility of conventional hedonic approaches to valuing non-market goods.

Perhaps most importantly, this paper has demonstrated that the combination of quasi-experiments and hedonic theory are a powerful method to use markets to value environmental and other non-market goods.

DATA APPENDIX

This data appendix provides information on a number of aspects of the data set that we compiled to conduct the analysis for this paper. Due to space constraints, this is an abridged version of the data appendix that is available in Greenstone and Gallagher (2005). The longer data appendix includes details on the variables on: the size of the hazardous waste sites; whether a site has achieved the construction complete designation; and the determination of expected and actual remediation costs. It also includes a discussion of how we placed hazardous waste sites in 2000 Census tracts and a lengthier discussion on the 1982 HRS sample.

I. Covariates in Housing Price and Rental Rate Regressions

The following are the control variables used in the housing price and rental rate regressions. They are listed by the categories indicated in the row headings at the bottom of these tables. All of the variables are measured in 1980 and are measured at the census tract level (or are the mean across sets of census tracts, for example tracts that share a border with a tract containing a hazardous waste site).

1980 Ln House Price
ln mean value of owner occupied housing units in 1980 (note: the median is unavailable in 1980)

1980 Housing Characteristics
total housing units (rental and owner occupied)
% of total housing units (rental and owner occupied) that are occupied
total housing units owner occupied
% of owner occupied housing units with 0 bedrooms
% of owner occupied housing units with 1 bedroom
% of owner occupied housing units with 2 bedrooms
% of owner occupied housing units with 3 bedrooms
% of owner occupied housing units with 4 bedrooms
% of owner occupied housing units with 5 or more bedrooms
% of owner occupied housing units that are detached
% of owner occupied housing units that are attached
% of owner occupied housing units that are mobile homes
% of owner occupied housing units built within last year
% of owner occupied housing units built 2 to 5 years ago
% of owner occupied housing units built 6 to 10 years ago
% of owner occupied housing units built 10 to 20 years ago
% of owner occupied housing units built 20 to 30 years ago
% of owner occupied housing units built 30 to 40 years ago
% of owner occupied housing units built more than 40 years ago
% of all housing units without a full kitchen
% of all housing units that have no heating or rely on a fire, stove, or portable heater
% of all housing units without air conditioning
% of all housing units without a full bathroom

Note: In the rental regressions in Table 6, the owner occupied variables are replaced with renter occupied versions of the variables. For example, the first variable is replaced with the "% of renter occupied housing units with 0 bedrooms."

1980 Economic Conditions

mean household income
% of households with income below poverty line
unemployment rate
% of households that receive some form of public assistance

1980 Demographics
population density
% of population Black
% of population Hispanic
% of population under age 18
% of population 65 or older
% of population foreign born
% of households headed by females
% of households residing in same house as 5 years ago
% of individuals aged 16-19 that are high school drop outs
% of population over 25 that failed to complete high school
% of population over 25 that have a BA or better (i.e., at least 16 years of education)

II. Assignment of HRS Scores and their Role in the Determination of the NPL

The HRS test scores each pathway from 0 to 100, where higher scores indicate greater risk.[30] The individual pathway scores are calculated using a method that considers characteristics of the site as being included in one of three categories: waste characteristics, likelihood of release, and target characteristics. The final pathway score is a multiplicative function of the scores in these three categories. The logic is, for example, that if twice as many people are thought to be affected via a pathway then the pathway score should be twice as large.

The final HRS score is calculated using the following equation:

(1) HRS Score $= [(S^2_{gw} + S^2_{sw} + S^2_a) / 3]^{1/2}$,

where S_{gw}, S_{sw}, and S_a, denote the ground water migration, surface water migration, and air migration pathway scores, respectively.[31] As equation (1) indicates, the final score is the square root of the average of the squared individual pathway scores. It is evident that the effect of an individual pathway on the total HRS score is proportional to the pathway score.

It is important to note that HRS scores can't be interpreted as strict cardinal measures of risk. A number of EPA studies have tested how well the HRS represents the underlying risk levels based on cancer and non-cancer risks.[32] The EPA has concluded that the HRS test (at least from the late 1980s version) is an ordinal test but sites with scores within 4 points of each pose roughly comparable risks to human health (EPA 1991).[33]

From 1982-1995, the EPA assigned all hazardous waste sites with a HRS score of 28.5 or greater to the NPL. Additionally, the original legislation gave every state the right to place one site on the NPL without the site having to score at or above 28.5 on the HRS test. As of 2003, 38 states have used their

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[30] The capping of individual pathways and of attributes within each pathway is one limiting characteristic of the test. There is a maximum value for most scores within each pathway category. Also, if the final pathway score is greater than 100 then this score is reduced to 100. The capping of individual pathways creates a loss of precision of the test since all pathway scores of 100 have the same effect on the final HRS score but may represent different magnitudes of risk. See the EPA's *Hazard Ranking System Guidance Manual* for further details on the determination of the HRS score.

[31] In 1990, the EPA revised the HRS test so that it also considers soil as an additional pathway.

[32] See Brody (1998) for a list of EPA studies that have examined this issue.

[33] The EPA states that the early 1980s version of the HRS test should not be viewed as a measure of "absolute risk", but that "the HRS does distinguish relative risks among sites and does identify sites that appear to present a significant risk to public health, welfare, or the environment" (Federal Register 1984).

exception. It is unknown whether these sites would have received a HRS score above 28.5. Six of these "state priority sites" were included on the original NPL released in 1983, but due to their missing HRS scores these six sites are excluded from this paper's analysis.

In 1995 the criteria for placement on the NPL were altered so that a site must have a HRS score greater than 28.5 and the governor of the state in which the site is located must approve the placement. There are currently a number of potential NPL sites with HRS scores greater than 28.5 that have not been proposed for NPL placement due to known state political opposition. We do not know the precise number of these sites because our Freedom of Information Act request for information about these sites was denied by the EPA.

III. Primary Samples of Hazardous Waste Sites

The paper relies on two primary samples of hazardous waste sites, which we label the "All NPL Sample" and the "1982 HRS Sample."

A. All NPL Sample

The All NPL sample includes NPL sites located in the 50 US states and the District of Columbia that were placed on the NPL before January 1, 2000. Although there are NPL sites located in US territories such as Puerto Rico, they are not included in the sample because the census data from these areas differs from the data for the remainder of the country. Further, the sample is limited to sites that were listed on the NPL before January 1, 2000 to ensure that site listing occurred before any data collection for the 2000 census. There are 1,398 sites in this sample.

B. 1982 HRS Sample

The second sample consists of the 690 sites that were tested between 1980 and 1982 for inclusion on the initial National Priority List announced on September 8, 1983. In this sample, sites that received a HRS scored exceeding 28.5 were placed on the NPL. See Greenstone and Gallagher (2005) for a more extensive discussion about some of the details surrounding the first NPL and this sample, more generally.

IV. Matching of 2000 Census Tracts to 1980 and 1990 Censuses

The census tract is used as the unit of analysis, because it is the smallest aggregation of data that is available in the 1980, 1990 and 2000 US Census. As noted in the text, year 2000 census tract boundaries are fixed so that the size and location of the census tract is the same for the 1980 and 1990 census data. The fixed census tract data boundaries were provided by Geolytics, a private company. Information on how the 1980 and 1990 census tracts were adjusted to fit the 2000 census tract boundaries can be found on their website at: www.geolytics.com.

An outline of their approach is as follows. Geolytics mapped 1990 census tracts into 2000 census tracts using block level data. Their documentation states, "The basic methodology was to use the smaller blocks to determine the population-weighted proportion of a 1990 tract that was later redefined as part of a 2000 tract."[34] A 1990 street coverage file was used to weight populations of 1990 blocks included in 2000 census tracts when the 1990 blocks were split among multiple census tracts. The assumption is that local streets and roads served as a proxy for where populations were located. Block level data for 1980 were unavailable. This complicated the mapping of 1980 tracts into 1990 tracts. However, the correspondence between 1980 tracts and 1990 blocks is "very good." As such "splitting a 1980 tract into 1990 tracts had to be done spatially, meaning based solely on the 1990 block to 1980 tract correspondence."[35]

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[34] Appendix J: Description of Tract Remapping Methodology of Geolytics Data Users' Guide for Neighborhood Change Database (1970-2000), page J3.

[35] Ibid, page J4.

V. Neighbor Samples

We use two approaches to define the set of houses outside each site's tract that may be affected by the clean-up. We refer to these sets of houses as "neighbors."

The first approach defines the neighbors as all census tracts that share a border with the tract that contains the site. GIS software was used to find each primary census tract and extract the identity of its adjacent neighbors. In the 1982 HRS sample, the maximum number of neighboring census tracts is 21 and the median is 7. The population of each adjacent census tract was used to weight the housing price, housing characteristics, and demographic variables for each tract when calculating the mean adjacent neighbor values.

The second approach defines neighbors based on circles of varying radii around the exact location of the site. GIS software is used to draw a circle around the point representing the site (generally the center of the site, but sometimes the point associated with the street address). For example in the 1 mile sample, the GIS program draws circles with radii of 1 mile around each of the sites. For a given site, data from all census tracts that fall within its 1-mile radius circle (including the tract containing the site) are used to calculate the mean housing values, housing and demographic characteristics, and economic variables. To calculate these weighted means, each census tract within the circle is weighted by the product of its population and the portion of its total area that falls within the circle. The maximum number of census tracts included in the 1 mile ring for a site is 37 and the mean and median are 3.9 and 3. For the 2 (3) mile ring the maximum number of neighbor sites is 80 (163), with a mean and median of 9.9 and 8 (18.2 and 12).

REFERENCES

Altonji, Joseph G., Todd E. Elder, and Christopher R. Taber, "Selection on Observed and Unobserved Variables: Assessing the Effectiveness of Catholic Schools," NBER Working Paper No. 7831, 2000.

Ashenfelter, Orley and Michael Greenstone, "Estimating the Value of a Statistical Life: The Importance of Omitted Variables and Publication Bias," *American Economic Review,* XCIV (May 2004), 454-60.

Banzhaf, H. Spencer and Randall P. Walsh, "Do People Vote with Their Feet: An Empirical Test of Environmental Gentrification," Mimeograph, 2005.

Bartik, Timothy J. "The Estimation of Demand Parameters in Hedonic Price Models." *Journal of Political Economy*, 95 (1987), 81-88.

Bartik, Timothy J. "Measuring the Benefits of Amenity Improvements in Hedonic Price Models." *Land Economics*, 64 (1988), 172-83.

Bayer, Patrick, Nathaniel Keohane, and Christopher Timmins. "Migration and Hedonic Valuation: The Case of Air Quality." Mimeograph, February 2006.

Black, Dan A. and Thomas J. Kneisner, "On the Measurement of Job Risk in Hedonic Wage Models," *Journal of Risk and Uncertainty,* XXVII (Dec. 2003), 205-20.

Black, Sandra, "Do Better Schools Matter? Parental Valuation of Elementary Education," *Quarterly Journal of Economics*, CXIV (May 1999), 577-99.

Brody, Thomas M., "Investing in Cleanup: A New Look at Decision Criteria for the Comparison and Management of Risk," Dissertation, Northwestern University, 1998.

Cameron, Trudy Ann and Ian T. McConnaha, "Evidence of Environmental Migration," Mimeograph, 2005.

Champ, Patricia A., Kevin J. Boyle and Thomas C. Brown, eds., *A Primer on Nonmarket Valuation*, (Dordrecht, The Netherlands: Kluwer Academic Publishers, 2003).

Chay, Kenneth Y., and Michael Greenstone, "Does Air Quality Matter? Evidence from the Housing Market," *Journal of Political Economy*, CXIII (Apr. 2005), 376-424.

Cleveland, William S., "Robust Locally Weighted Regression and Smoothing Scatterplots," *Journal of the American Statistical Association*, LXXIV (Dec. 1979), 829-36.

Cook, Thomas D., and Donald T. Campbell, *Quasi-Experimentation: Design and Analysis Issues for Field Settings*, (Boston, MA: Houghton Mifflin, 1979).

Cropper, Maureen L., Leland B. Deck, and Kenneth E. McConnell, "On the Choice of Functional Form for Hedonic Price Functions," *Review of Economics and Statistics,* LXX (Nov. 1988), 668-75.

Currie, Janet, Michael Greenstone, and Enrico Moretti, "Are Hazardous Waste Sites Hazardous to Human Health? Evidence from Superfund Clean-Ups and Infant Health," Mimeograph, 2006.

Davis, Lucas, "The Effect of Health Risk on Housing Values: Evidence from a Cancer Cluster,"

American Economics Review, XCIV (Dec. 2004), 1693-1704.

Deschenes, Olivier and Michael Greenstone, "The Economic Impacts of Climate Change: Evidence from Agricultural Profits and Random Fluctuations in Weather," American Economic Review, (forthcoming) 2006.

Diamond, Peter A. and Jerry A. Hausman, "Contingent Valuation: Is Some Number Better Than No Number?" *Journal of Economic Perspectives*, VIII (Autumn 1994), 45-64.

Ekeland, Ivar, James J. Heckman, and Lars Nesheim, "Identification and Estimation of Hedonic Models," *Journal of Political Economy*, CXII (Feb. 2004), S60-S109.

Environmental Protection Agency, "National Priorities List for Uncontrolled Hazardous Waste Sites," Federal Register 5598 – 5605, Vol 56, No 28; Feb 11, 1991.

Environmental Protection Agency, *Superfund: 20 Years of Protecting Human Health and the Environment*, "http://www.epa.gov/superfund/action/20years/index.htm," 2000.

Environmental Protection Agency, 2006 SUPERFUND BENEFITS ANALYSIS……

Epple, Dennis, "Hedonic Prices and Implicit Markets: Estimating Demand and Supply Functions for Differentiated Products," *Journal of Political Economy*, 95 (1987), 59-80.

Farrell, Alex, "A Partial Benefit-Cost Test of NPL Site Remediation: Benefit Transfer with Met-Analytic Hedonic Data," Mimeograph, University of California, Berkeley, 2004.

Federal Register Rules and Regulations, "National Oil and Hazardous Substance Contingency Plan; The National Priorities List; Amendment," Various Issues.

Federal Register Rules and Regulations, "Environmental Protection Agency. 40 CFR Part 300 National Oil and Hazardous Substances Contingency Plan [SWH-FRL 2163-4] 47 FR 31180," (July 16, 1982).

Federal Register Rules and Regulations, "Environmental Protection Agency. 40 CFR Part 300 [SWH-FRL-2646-2] Amendment to National Oil and Hazardous Substance Contingency Plan; National Priorities List," Vol. 49, No. 185 (September 21, 1984).

Freeman, A Myrick, III, "On Estimating Air Pollution Control Benefits from Land Value Studies, Journal *of Environmental Economics and Management*, I (May 1974), 74-83.

----, *The Measurement of Environmental and Resource Values*, (Washington, DC: Resources for the Future, 2003).

Gayer, Ted, James T. Hamilton, and W. Kip Viscusi, "Private Values of Risk Tradeoffs at Superfund Sites: Housing Market Evidence on Learning about Risk," The *Review of Economics and Statistics*, LXXXII (Aug. 2000), 439-51.

----, "The Market Value of Reducing Cancer Risk: Hedonic Housing Prices with Changing Information," *Southern Economic Journal*, LXIX (Oct. 2002), 266-89.

Glaeser, Edward L. and Joseph Gyourko. "The Impacts of Building Restriction on Housing Affordability." Federal Reserve Board of New York. Economic Policy Review June 2003. pp. 21-

39.

Greenstone, Michael and Justin Gallagher, "Does Hazardous Waste Matter? Evidence from the Housing Market and the Superfund Program," NBER Working Paper No. 11790, 2005.

Gupta, Shreekant, George Van Houtven, and Maureen Cropper, "Do Benefits and Costs Matter in Environmental Regulation? An Analysis of EPA Decisions under Superfund," *Analyzing Superfund: Economics, Science, Law*, Richard L. Revesz and Richard B. Stewart eds., (Washington, DC: Resources for the Future, 1995).

----, "Paying for Permanence: An Economic Analysis of EPA's Cleanup Decisions at Superfund Sites," *RAND Journal of Economics*, XXVII (Autumn 1996), 563-82.

Halvorsen, Robert and Henry O. Pollakowski, "Choice of Functional Form for Hedonic Price Equations," *Journal of Urban Economics*, X (Jul. 1981), 37-49.

Hanemann, W. Michael, "Valuing the Environment through Contingent Valuation," *Journal of Economic Perspectives*, VIII (Autumn 1994), 19-43.

Harris, John D., "Property Values, Stigma, and Superfund," Environmental Protection Agency, "http://www.epa.gov/superfund/programs/recycle/property.htm," 1999.

Ihlanfeldt, Keith R. and Laura O. Taylor, "Externality Effects of Small-Scale Hazardous Waste Sites: Evidence from Urban Commercial Property Markets," XLVII (January 2004), 117-39.

Kiel, Katherine A., "Measuring the Impact of the Discovery and Cleaning of Identified Hazardous Waste Sites on House Values," *Land Economics*, LXXI (Nov. 1995), 428-35.

Kiel, Katherine A. and Jeffery Zabel, "Estimating the Economic Benefits of Cleaning Up Superfund Sites: The Case of Woburn, Massachusetts," *The Journal of Real Estate Finance & Economics*, XXII (Mar. 2001), 163-84.

Kohlhase, Janet E., "The Impact of Toxic Waste Sites on Housing Values," *Journal of Urban Economics*, XXX (Jul. 1991), 1-26.

Linden, Leigh L. and Jonah E. Rockoff, "There Goes the Neighborhood? Estimates of the Impact of Crime Risk on Property Values from Megan's Law," NBER Working Paper No. 12253, 2006.

McCluskey, Jill J. and Gordon C. Rausser, "Hazardous Waste Sites and Housing Appreciation Rates," Journal *of Environmental Economics and Management*, XLV (Jul. 2003), 166-176.

Messer, Kent, William Schulze, Katherine Hackett, Trudy Cameron, and Gary McClelland, "Stigma: The Psychology and Economics of Superfund," Working Paper, 2004.

Michaels, R. Gregory and V. Kerry Smith, "Market Segmentation and Valuing Amenities with Hedonic Models: The Case of Hazardous Waste Sites," *Journal of Urban Economics*, XXVIII (Sep. 1990), 223-42.

Probst, Katherine N. and David M. Konisky, *Superfund's Future: What Will It Cost?* (Washington, DC: Resources for the Future, 2001).

Ridker, Ronald, *The Economic Cost of Air Pollution*, (New York, NY: Prager, 1967).

---- and J.A. Henning, "The Determinants of Residential Property Values with Special Reference to Air Pollution," *Review of Economics and Statistics*, XLIX (May 1967), 246-57.

Roback, Jennifer, "Wages, Rents, and the Quality of Life," *Journal of Political Economy*, XC (Dec. 1982), 1257-78.

Rosen, Sherwin, "Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition," *Journal of Political Economy*, LXXXII (Jan. 1974), 34-55.

----, "The Theory of Equalizing Differences," *Handbook of Labor Economics,* Orley Ashenfelter and Richard Layard, eds., (Amsterdam: North-Holland, 1986).

Schmalensee, Richard, Ramachandra Ramanathan, Wolfhard Ramm, and Dennis Smallwood, *Measuring External Effects of Solid Waste Management*, (Washington DC: Environmental Protection Agency, 1975).

Sigman, Hilary, "The Pace of Progress at Superfund Sites: Policy Goals and Interest Group Influence," *Journal of Law and Economics*, XLIV (Apr. 2001), 315-44.

Small, Kenneth A., "Air Pollution and Property Values: A Further Comment," *Review of Economics and Statistics*, LVII (Feb. 1975), 105-7.

Viscusi, W. Kip and James T. Hamilton, "Are Risk Regulators Rational? Evidence from Hazardous Waste Cleanup Decisions," *American Economic Review*, LXXXIX (Sep. 1999), 1010-27.

Vrijheid, Martine, "Health Effects of Residence Near Hazardous Waste Landfill Sites: A Review of Epidemiologic Literature," *Environmental Health Perspectives Supplements* 108 No. S1 (March 2000: 101-12.

Zimmerman, Rae, "Social Equality and Environmental Risk," *Risk Analysis*, XIII (Dec. 1993), 649-66.

Table 1: Summary Statistics on the Superfund Program

	All NPL Sites w/ non-Missing House Price Data (1)	1982 HRS Sites w/ non-Missing House Price Data (2)	1982 HRS Sites w/ Missing House Price Data (3)
Number of Sites	985	487	189
1982 HRS Score Above 28.5	------	306	95
	A. Timing of Placement on NPL		
Total	985	332	111
# 1981-1985	406	312	97
# 1986-1989	340	14	9
# 1990-1994	166	4	3
# 1995-1999	73	2	2
	B. HRS Information		
Mean Scores | HRS $\geq$ 28.5	41.89	44.47	43.23
Mean Scores | HRS < 28.5	-----	15.54	16.50
	C. Size of Site (in acres)		
Number of sites with size data	920	310	97
Mean (Median)	1,186 (29)	334 (25)	10,507 (35)
Maximum	195,200	42,560	405,760
	D. Stages of Clean-Up for NPL Sites		
Median Years from NPL Listing Until:			
ROD Issued	------	4.3	4.3
Clean-Up Initiated	------	5.8	6.8
Construction Complete	------	12.1	11.5
Deleted from NPL	------	12.8	12.5
1990 Status Among Sites NPL by 1990			
NPL Only	394	100	31
ROD Issued or Clean-up Initiated	335	210	68
Construction Complete or Deleted	22	16	7
2000 Status Among Sites NPL by 2000			
NPL Only	137	15	3
ROD Issued or Clean-up Initiated	370	119	33
Construction Complete or Deleted	478	198	75
	E. Expected Costs of Remediation (Millions of 2000 $'s)		
# Sites with Nonmissing Costs	753	293	95
Mean (Median)	$28.3 ($11.0)	$27.5 ($15.0)	$29.6 ($11.5)
95th Percentile	$89.6	$95.3	$146.0
	F. Actual and Expected Costs Conditional on Construction Complete (Millions of 2000 $'s)		
Sites w/ Both Costs Nonmissing	477	203	69
Mean (Median) Expected Costs	$15.5 ($7.8)	$20.6 ($9.7)	$17.3 ($7.3)
Mean (Median) Actual Costs	$21.6 ($11.6)	$32.0 ($16.2)	$23.3 ($8.9)

Notes: All dollar figures are in 2000 $'s. Column (1) includes information for sites placed on the NPL before 12/31/99. The estimated cost information is calculated as the sum across the first Record of Decisions for each operating unit associated with a site. See the Data Appendix for further details.

Table 2: Mean Census Tract Characteristics by Categories of the 1982 HRS Score

	NPL Site by 2000 (1)	No NPL Site by 2000 (2)	HRS < 28.5 (3)	HRS > 28.5 (4)	HRS > 16.5 & < 28.5 (5)	HRS > 28.5 & < 40.5 (6)	P-Value (1) vs. (2) (7)	P-Value (3) vs. (4) (8)	P-Value (5) vs. (6) (9)
# Census Tracts	985	41,989	181	306	90	137	-----	-----	-----
Superfund Clean-up Activities									
Ever NPL by 1990	0.7574	-----	0.1271	0.9902	0.2222	0.9854	-----	**0.000**	**0.000**
Ever NPL by 2000	1.0000	-----	0.1602	0.9902	0.2667	0.9854	-----	**0.000**	**0.000**
Housing Prices									
1980 Mean	58,045	69,904	45,027	52,137	46,135	50,648	**0.000**	**0.000**	0.084
1990 Median	100,066	99,552	80,185	96,752	84,462	91,611	0.850	**0.005**	0.433
2000 Median	139,041	151,712	115,479	135,436	117,528	123,503	**0.000**	**0.001**	0.449
Housing Prices in Census Tracts that Share a Border with the Tracts Containing the Hazardous Waste Site									
1980 Mean	61,078	-----	48,185	53,037	48,594	52,415	-----	0.014	0.179
1990 Median	100,840	-----	84,624	94,324	86,982	85,950	-----	0.053	0.879
2000 Median	143,974	-----	121,294	134,309	125,019	123,462	-----	0.031	0.845
1980 Housing Characteristics									
Total Housing Units	1,392	1,350	1,357	1,353	1,367	1,319	0.039	0.951	0.575
% Mobile Homes	0.0862	0.0473	0.0813	0.0785	0.0944	0.0787	**0.000**	0.792	0.285
% Occupied	0.9408	0.9330	0.9408	0.9411	0.9412	0.9411	**0.000**	0.940	0.989
% Owner Occupied	0.6818	0.6125	0.6792	0.6800	0.6942	0.6730	**0.000**	0.959	0.344
% 0-2 Bedrooms	0.4484	0.4722	0.4691	0.4443	0.4671	0.4496	**0.000**	0.107	0.417
% 3-4 Bedrooms	0.5245	0.5016	0.5099	0.5288	0.5089	0.5199	**0.000**	0.202	0.586
% Built Last 5 Years	0.1434	0.1543	0.1185	0.1404	0.1366	0.1397	**0.006**	0.050	0.844
% Built Last 10 Years	0.2834	0.2874	0.2370	0.2814	0.2673	0.2758	0.506	0.012	0.723
% No Air Conditioning	0.4903	0.4220	0.5058	0.4801	0.5157	0.5103	**0.000**	0.253	0.870
% with Zero Full Baths	0.0254	0.0229	0.0315	0.0259	0.0339	0.0290	0.011	0.089	0.386
% Units Detached	0.8764	0.8773	0.8585	0.8908	0.8545	0.8897	0.868	0.050	0.107
% Units Attached	0.0374	0.0754	0.0603	0.0307	0.0511	0.0317	**0.000**	0.040	0.297
1980 Demographics & Economic Characteristics									
Population Density	1,407	5,786	1,670	1,157	1,361	1,151	**0.000**	0.067	0.570
% Black	0.0914	0.1207	0.1126	0.0713	0.0819	0.0844	**0.000**	0.037	0.926
% Hispanic	0.0515	0.0739	0.0443	0.0424	0.0309	0.0300	**0.000**	0.841	0.928
% Under 18	0.2939	0.2780	0.2932	0.2936	0.2885	0.2934	**0.000**	0.958	0.568
% Female Head HH	0.1616	0.1934	0.1879	0.1576	0.1639	0.1664	**0.000**	0.017	0.862
% Same House 5 Yrs Ago	0.5442	0.5127	0.6025	0.5623	0.5854	0.5655	**0.000**	**0.001**	0.244
% > 25 No HS Diploma	0.3427	0.3144	0.4053	0.3429	0.3881	0.3533	**0.000**	**0.000**	0.060

% > 25 BA or Better	0.1389	0.1767	0.1003	0.1377	0.1092	0.1343	**0.000**	**0.000**	0.036
% < Poverty Line	0.1056	0.1141	0.1139	0.1005	0.1072	0.1115	**0.003**	0.109	0.716
% Public Assistance	0.0736	0.0773	0.0885	0.0745	0.0805	0.0755	0.084	0.041	0.578
Household Income	20,340	21,526	19,635	20,869	19,812	20,301	**0.000**	0.013	0.486
1980 Geographic Distribution Across Census Regions									
% Northeast	0.3797	0.2116	0.3315	0.4771	0.3889	0.4234	**0.000**	**0.001**	0.6063
% Midwest	0.2183	0.2320	0.3481	0.2255	0.3222	0.2847	0.302	**0.004**	0.5507
% South	0.2355	0.3227	0.2155	0.1928	0.1889	0.2044	**0.000**	0.552	0.7744
% West	0.1665	0.2337	0.1050	0.1046	0.1000	0.0876	**0.000**	0.989	0.7565

Notes: Columns (1) - (6) report the means of the variables listed in the row headings across the groups of census tracts listed at the top of the columns. In all of these columns, the sample restriction that the census tract must have nonmissing house price data in 1980, 1990, and 2000 is added. Columns (7)-(9) report the p-values from tests that the means in different sets of the subsamples are equal. The Panel title "Neighbor Housing Price" reports the mean housing prices in all tracts that share a border with the tract containing the hazardous waste site—the sample sizes differ slightly in this panel (they are 984, 177, 306, 89, and 137, respectively) as a few of these tracts are surrounded by water so they don't share a border with another tract. All other entries in the table refer to characteristics of the tracts where the sites are located (except the column 2 entries which report the means in tracts without a site). P-values less than .01 are denoted in bold. For the air conditioning and bath questions, the numerator is year round housing units and the denominator is all housing units. For all other variables in the "Housing Characteristics" category, the denominator is all housing units. In contrast to the remainder of the paper, the dollar figures are not adjusted for inflation.

Table 3: Least Squares Estimates of the Association Between NPL Status and House Prices

	(1)	(2)	(3)	(4)
A. All NPL Sample, Own Census Tract Observation				
1(NPL Status by 2000)	0.040	0.046	0.073	0.067
	(0.012)	(0.011)	(0.010)	(0.009)
R-squared	0.579	0.654	0.731	0.779
B. All NPL Sample, 3-Mile Radius Circle Sample Obsevation				
1(NPL Status by 2000)	0.030	0.059	0.113	0.106
	(0.011)	(0.013)	(0.012)	(0.011)
Ho: > 0.045, P-Value	0.076	0.726	0.999	0.999
R-squared	0.580	0.652	0.727	0.776
C. Restrict NPL Sites to those in 1982 HRS Sample, Own Census Tract Observation				
1(NPL Status by 2000)	0.071	0.076	0.085	0.057
	(0.016)	(0.015)	(0.014)	(0.013)
R-squared	0.581	0.655	0.732	0.780
D. Restrict NPL Sites to those in 1982 HRS Sample, 3-Mile Radius Circle Sample Observation				
1(NPL Status by 2000)	0.046	0.145	0.232	0.194
	(0.015)	(0.022)	(0.023)	(0.022)
Ho: > 0.054, P-Value	0.302	0.999	0.999	0.999
R-squared	0.580	0.653	0.728	0.777
1980 Prices	Yes	Yes	Yes	Yes
1980 Housing Characteristics	No	Yes	Yes	Yes
1980 Economic and Demographic Variables	No	No	Yes	Yes
State Fixed Effects	No	No	No	Yes

Notes: The table reports results from 16 separate regressions. The sample size is 42,974 in Panels A and B and 42,321 in Panels C and D. In Panel A/B (C/D) 985 (332) observations are from an area containing a hazardous waste site that had been on the NPL at any time prior to the 2000 observation on housing prices. The difference between A/B and C/D is that C/D drops observations from areas with the 663 NPL sites that were not tested for inclusion in the initial NPL. The remainder of the sample is comprised of the 41,989 observations on census tracts with complete housing price data that neither have a NPL site nor are adjacent to a tract with a NPL site. In Panels A/C the NPL unit of observation is the tract that contains the site and in B/D it is based on the census tracts that fall within circles centered at the site with a radius of 3 miles. For these circle-based observations, the dependent and independent variables are calculated as weighted means across the tracts inside the circle, where the weight is the fraction of the tract's land area inside the circle multiplied by the tract's 1980 population. The entries report the coefficient and heteroskedastic-consistent standard error (in parentheses) on the NPL indicator, as well as the R-squared statistic. Panels B and D also report p-values from tests of whether the NPL parameters multiplied by the 1980 aggregate value of the housing stock exceeds \$39 million (Panel B) and \$42 million (Panel D), which is our best estimate of the cost of the average clean-up in these samples. The aggregate values of the housing stocks in B and D are \$874 and \$796 million, respectively. The controls are listed in the row headings at the bottom of the table. See the text and Data Appendix for further details.

Table 4: Two-Stage Least Squares (2SLS) Estimates of the Effect of NPL Status on House Prices

	(1)	(2)	(3)	(4)	(5)	(6)
	A. Own Census Tract					
1(NPL Status by 2000)	0.037	0.043	0.056	0.047	0.007	0.027
	(0.035)	(0.031)	(0.029)	(0.027)	(0.063)	(0.038)
	B. Adjacent Census Tracts					
1(NPL Status by 2000)	0.066	0.012	0.011	0.015	-0.006	0.001
	(0.035)	(0.029)	(0.025)	(0.022)	(0.056)	(0.035)
	C. 2 Mile Radius from Hazardous Waste Sites					
1(NPL Status by 2000)	0.018	0.013	0.018	0.003	0.018	-0.008
	(0.032)	(0.029)	(0.026)	(0.023)	(0.053)	(0.033)
Ho: > 0.123, P-Value	0.001	0.000	0.000	0.000	0.024	0.000
	D. 3 Mile Radius from Hazardous Waste Sites					
1(NPL Status by 2000)	0.056	0.036	0.027	0.001	-0.027	-0.005
	(0.038)	(0.031)	(0.026)	(0.022)	(0.052)	(0.034)
Ho: > 0.054, P-Value	0.482	0.282	0.153	0.008	0.058	0.041
1980 Ln House Price	Yes	Yes	Yes	Yes	Yes	Yes
1980 Housing Characteristics	No	Yes	Yes	Yes	Yes	Yes
1980 Economic & Demographic Vars	No	No	Yes	Yes	Yes	Yes
State Fixed Effects	No	No	No	Yes	Yes	Yes
Quadratic in 1982 HRS Score	No	No	No	No	Yes	No
Regression Discontinuity Sample	No	No	No	No	No	Yes

Notes: The entries report the results from 24 separate instrumental variables regressions. The ln (2000 median house price) is the dependent variable throughout the table. The units of observation are the census tract that contains the site (Panel A), tracts that share a border with the site (Panel B), the areas within a circle of 2 mile radius from the site (Panel C), and the areas within a circle of 3 mile radius from the site (Panel D). In Panels B-D where the unit of observation is comprised of multiple census tracts, the dependent and independent variables are calculated as weighted means across the relevant census tracts where the weight is the fraction of the tract that fits the Panel's sample selection rule multiplied by the tract's 1980 population. The variable of interest is an indicator for NPL status and this variable is instrumented with an indicator for whether the tract had a hazardous waste site with a 1982 HRS score exceeding 28.5. The entries are the regression coefficients and heteroskedastic consistent standard errors (in parentheses) associated with the NPL indicator. In Panel A (B-D) the samples sizes are 487 (483) in columns (1) through (5) and 227 (226) in column (6). Panels C and D also report p-values from tests of whether the NPL parameters multiplied by the 1980 value of total housing exceeds \$43 million, which is our best estimate of the cost of the average clean-up. The 1980 aggregate values of the housing stock in the four panels are roughly \$71, \$525, \$349, and \$796 million (2000 \$'s). See the notes to Table 3, the text and the Data Appendix for further details.

Table 5: Further 2SLS Estimates of the Effect of NPL Status on 2000 House Prices, 2-Mile Radius Sample

	(1)	(2)	(3)	(4)
A. Add Controls for Ground Water, Surface Water, and Air Migration Pathway Scores				
1(NPL Status by 2000)	-0.033	-0.021	0.028	0.021
	(0.050)	(0.034)	(0.053)	(0.061)
B. Add Controls for 2000 Covariates				
1(NPL Status by 2000)	0.018	-0.011	-0.046	-0.020
	(0.032)	(0.020)	(0.044)	(0.031)
C. Dependent Variable is 1990 Housing Prices				
1(NPL Status by 1990)	0.019	-0.019	-0.000	-0.040
	(0.048)	(0.033)	(0.070)	(0.056)
D. Does Effect of NPL Status Differ in Tracts in Top Quartile of Population Density?				
1(NPL Status by 2000)	0.048	0.015	0.027	0.006
	(0.036)	(0.027)	(0.056)	(0.041)
1(2000 NPL)*1(Top Quartile Density)	-0.072	-0.043	-0.040	-0.040
	(0.072)	(0.047)	(0.047)	(0.067)
1980 Ln House Price	Yes	Yes	Yes	Yes
1980 Housing Characteristics	No	Yes	Yes	Yes
1980 Economic and Demographic Variables	No	Yes	Yes	Yes
State Fixed Effects	No	Yes	Yes	Yes
Quadratic in 1982 HRS Score	No	No	Yes	No
Regression Discontinuity Sample	No	No	No	Yes

Notes: Each panel reports parameter estimates and standard errors from 4 separate regressions for 2000 housing prices. The panels differ from the Table 4 specifications in the following ways: A. adds controls for the individual pathway scores that are used to calculate the HRS score; B. adds controls for the 2000 values of the covariates; C. tests for the impact of NPL status on housing prices in 1990; and D. allows the effect of NPL status to differ in census tracts in the top quartile of population density. In all panels, the sample is the 2-mile radius one and the sample sizes are 483 in columns (1) through (3) and 226 in column (4). See the Notes to Table 4 and the text for further details.

Table 6: 2SLS Estimates of Stages of Superfund Clean-ups on Rental Rate Growth, 2-Mile Radius Sample

	(1)	(2)	(3)	(4)
1(NPL Only)	0.124	-0.019	-0.043	-0.053
[115 Sites, Mean HRS = 40.2]	(0.046)	(0.034)	(0.049)	(0.052)
1(ROD & Incomplete Remediation)	0.101	-0.023	-0.054	-0.083
[329 Sites, Mean HRS = 44.3]	(0.030)	(0.022)	(0.042)	(0.032)
1(Const Complete or NPL Deletion)	0.059	-0.001	-0.028	-0.037
[214 Sites, Mean HRS = 41.6]	(0.032)	(0.021)	(0.041)	(0.032)
P-Value from F-Test of Equality	0.25	0.48	0.36	0.31
1980 Rental Rate	Yes	Yes	Yes	Yes
1980 Housing Characteristics of Rental Units	No	Yes	Yes	Yes
1980 Economic and Demographic Variables	No	Yes	Yes	Yes
State Fixed Effects	No	Yes	Yes	Yes
Quadratic in 1982 HRS Score	No	No	Yes	No
Regression Discontinuity Sample	No	No	No	Yes

Notes: The entries report the results from 4 separate instrumental variables regressions. The ln (median rental rate) is the dependent variable throughout the table. There are two observations per county, one for 2000 and one for 1990. Here, the indicator variable for NPL status has been replaced by three independent indicator variables. They are equal to 1 for sites that by 1990 or 2000 were placed on the NPL but no ROD had been issued, issued a ROD but remediation was incomplete, and "construction complete" or deleted from the NPL, respectively. The instruments are the interactions of the indicator for a 1982 HRS score above 28.5 and these three independent indicators. The table reports the instrumental variables parameter estimates and standard errors clustered at the site level for the three indicators of clean-up status. The table also reports the p-value associated with a F-test that the three parameters are equal. The effect of all of the controls listed in the row headings are allowed to differ in 1990 and 2000. The sample sizes in columns (1) through (4) are 966, 960, 960, and 452, respectively. See the text for further details.

Table 7: IV Estimates of 2000 NPL Status on 2000 Demand Shifters, 2-Mile Radius Sample

	(1)	(2)	(3)	(4)
A. Income and Wealth				
Household Income				
[1980 Mean: 42,544; 2000 – 1980 Mean: 14,318]	2,758	1,514	-1,233	-563
	(1,232)	(1,289)	(3,078)	(2,255)
% Public Assistance				
[1980 Mean: 0.078; 2000 -1980 Mean: 0.000]	-0.007	-0.005	0.008	0.003
	(0.003)	(0.003)	(0.007)	(0.004)
% College Graduates				
[1980 Mean:0.135; 2000 -1980 Mean: 0.081]	0.002	-0.000	-0.009	-0.010
	(0.006)	(0.007)	(0.018)	(0.013)
B. Demographics Demand Shifters				
% Population Under Age 6				
[1980 Mean: 0.086; 2000 -1980 Mean: -0.018]	0.000	-0.000	0.002	0.001
	(0.001)	(0.001)	(0.003)	(0.002)
% Population Over Age 65				
[1980 Mean: 0.106; 2000 -1980 Mean: 0.019]	-0.001	-0.003	-0.014	-0.006
	(0.004)	(0.004)	(0.009)	(0.006)
% Black				
[1980 Mean: 0.088; 2000 -1980 Mean:0.027]	-0.015	-0.015	-0.006	-0.008
	(0.008)	(0.007)	(0.018)	(0.010)
C. Total Population				
Total Population	1,946	355	-2,304	-348
[1980 Mean: 19,517; 2000 – 1980 Mean: 1,526]	(577)	(559)	(1,613)	(876)
1980 Dependent Variable	Yes	Yes	Yes	Yes
State Fixed Effects	No	Yes	Yes	Yes
Quadratic in 1982 HRS Score	No	No	No	No
Regression Discontinuity Sample	No	No	Yes	Yes

Notes: The entries report the results from 28 separate instrumental variables regressions. The 2000 values of the variables underlined in the first column are the dependent variables. The unit of observation is the area within a circle of 2 mile radius from the hazardous waste site. The dependent and independent variables are calculated as weighted means across the census tracts within the 2 mile radius circle, where the weight is the fraction of the tract within the circle multiplied by the tract's 1980 population. The variable of interest is an indicator that equals 1 for observations from tracts with a hazardous waste site that was placed on the NPL by 2000 and this variable is instrumented with an indicator for whether the tract had a hazardous waste site with a 1982 HRS score exceeding 28.5. The entries are the regression coefficients and heteroskedastic consistent standard errors (in parentheses) associated with the NPL indicator. The samples sizes are 483 in columns (1) through (3) and 226 in column (4). The 1980 and 2000-1980 means of the dependent variables are reported in square brackets. See the text and previous tables for further details.

Table 8: 2SLS Estimates of the Effect of 2000 NPL Status on Housing Supply, 2- and 3- Mile Radius Samples

	(1)	(2)	(3)	(4)
Total Housing Units				
2 Mile Radius from Hazardous Waste Sites				
[1980 Mean: 7,363; 2000 – 1980 Mean: 1,013]	344	60	-889	-260
	(151)	(151)	(369)	(202)
3 Mile Radius from Hazardous Waste Sites				
[1980 Mean: 16,431; 2000- 1980 Mean: 2,187]	1,094	309	-907	-56
	(330)	(286)	(702)	(373)
1980 Dependent Variable and Ln House Price	Yes	Yes	Yes	Yes
1980 Housing Characteristics	No	Yes	Yes	Yes
1980 Economic and Demographic Variables	No	Yes	Yes	Yes
State Fixed Effects	No	Yes	Yes	Yes
Quadratic in 1982 HRS Score	No	No	Yes	No
Regression Discontinuity Sample	No	No	No	Yes

Notes: The entries report the results from 8 separate instrumental variables regressions. The dependent variables are the number of housing units. The results are reported for the cases where the units of observation are the areas within a circle of 2 and 3 mile radius from the site. The dependent and independent variables are calculated as weighted means across the relevant census tracts where the weight is the fraction of the tract that falls within the circle multiplied by the tract's 1980 population. The variable of interest is an indicator for NPL status and this variable is instrumented with an indicator for whether the tract had a hazardous waste site with a 1982 HRS score exceeding 28.5. The entries are the regression coefficients and heteroskedastic consistent standard errors (in parentheses) associated with the NPL indicator. The samples sizes are 483 in columns (1) through (3) and 226 in column (4). The means of the dependent variable in 1980 and the mean change between 2000 and 1980 are reported in square brackets in the first column. See the notes to Table 3, the text and the Data Appendix for further details.

Figure 1a: Bid Curves, Offer Curves, and the Equilibrium Hedonic Price Schedule in a Hedonic Market for Local Environmental Quality

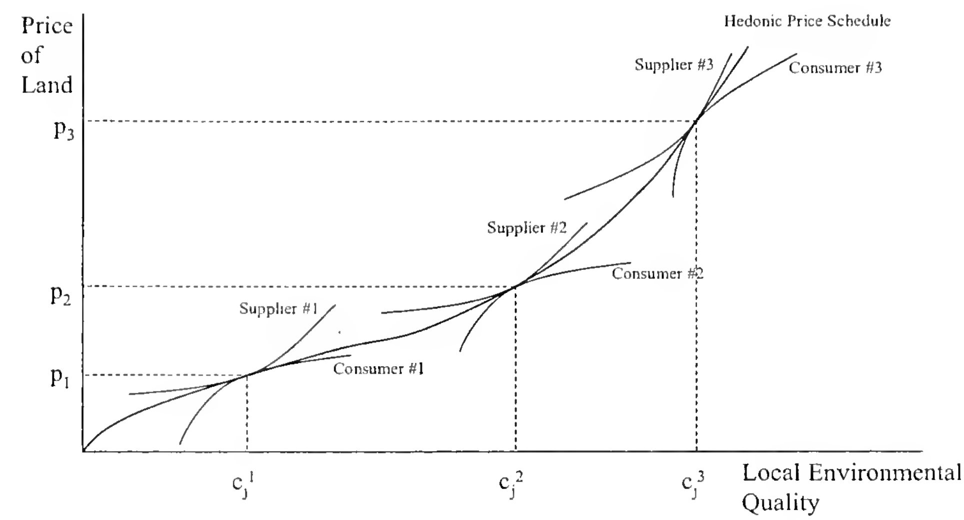


Figure 1b: Welfare Gains Due to Amenity Improvements with Two Supply Curves

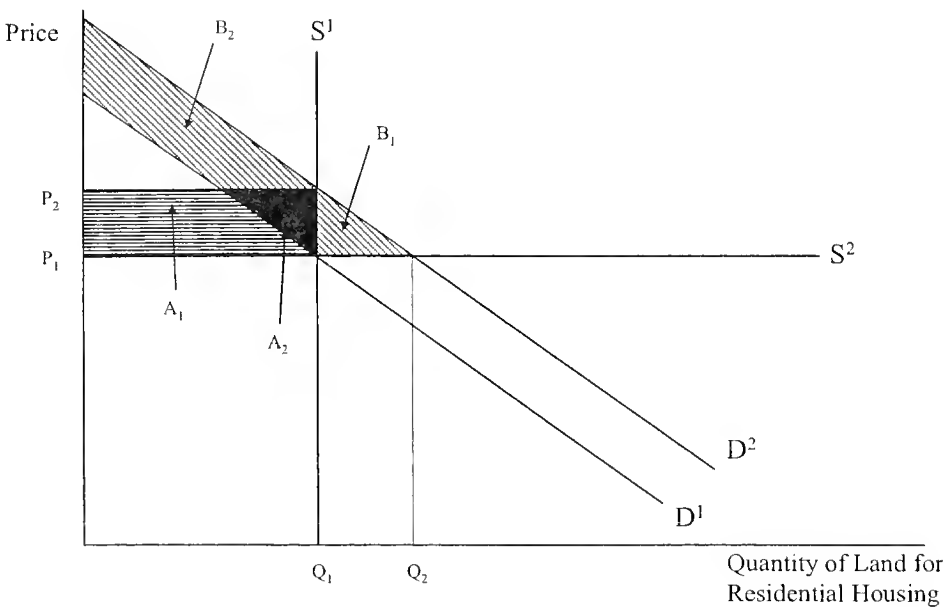


Figure 2: Geographic Distribution of NPL Hazardous Waste Sites in the All NPL Sample

Notes: The All NPL sample is comprised of the 985 hazardous waste sites assigned to the NPL by January 1, 2000 that we placed in a census tract with nonmissing housing price data in 1980, 1990, and 2000.

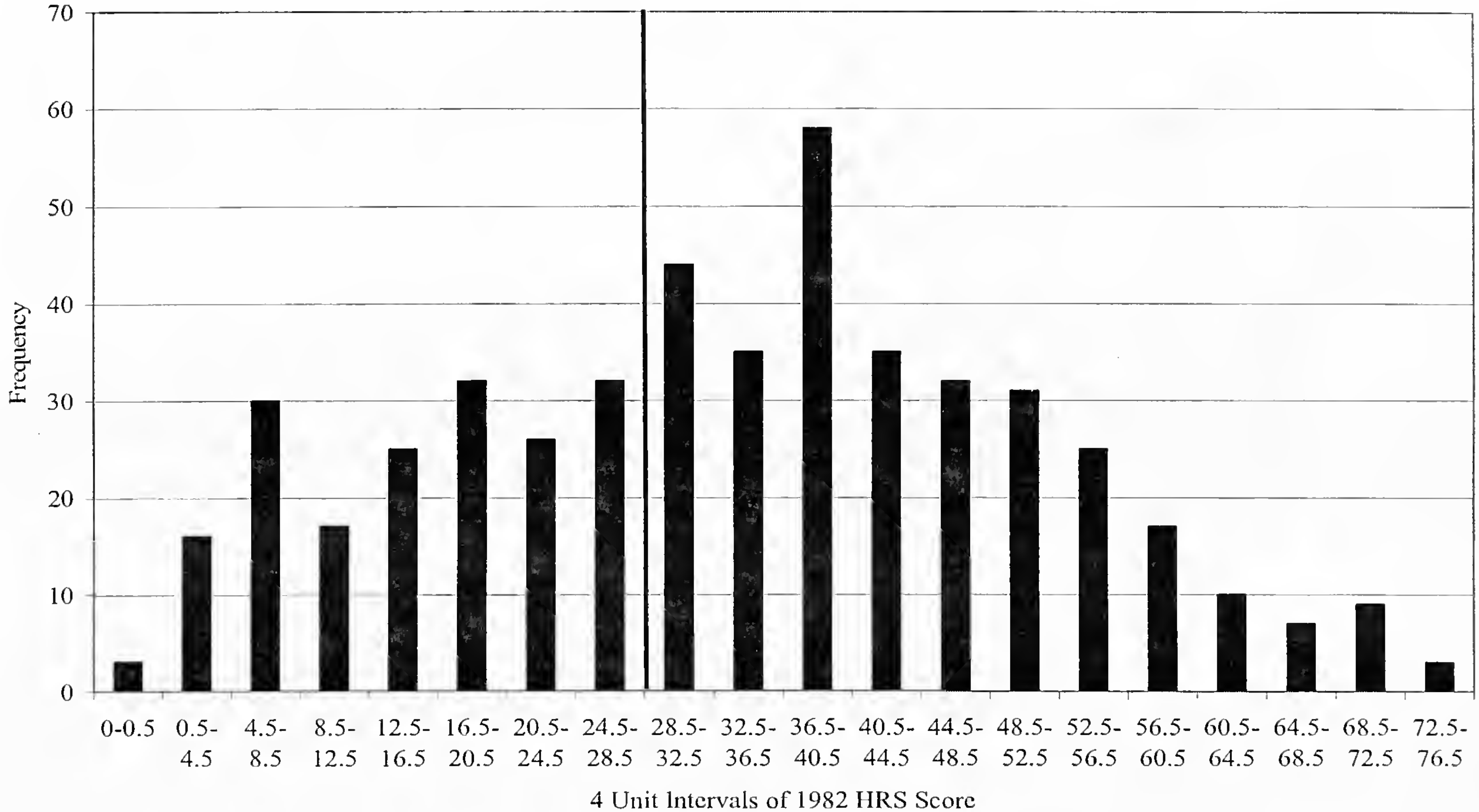
Figure 3: Geographic Distribution of Hazardous Waste Sites in the 1982 HRS Sample

A. Sites with 1982 HRS Scores Exceeding 28.5

B. Sites with 1982 HRS Scores Below 28.5

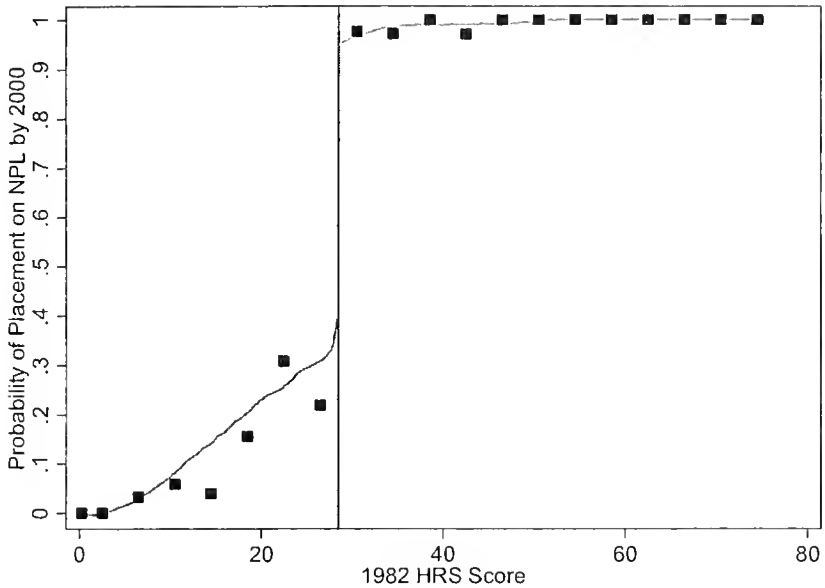
Notes: The 1982 HRS Sample is comprised of the 487 hazardous waste sites that were placed in a census tract with nonmissing housing price data in 1980, 1990, and 2000. 306 (181) of these sites had 1982 HRS scores above (below) 28.5.

Figure 4: Distribution of 1982 HRS Scores



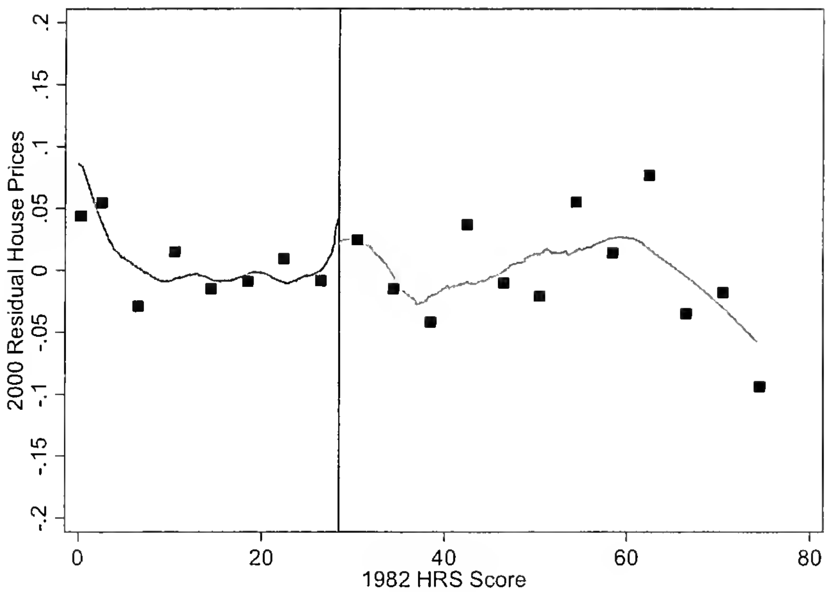
Notes: The figure displays the distribution of 1982 HRS scores among the 487 hazardous waste sites that were tested for placement on the NPL after the passage of the Superfund legislation but before the announcement of the first NPL in 1983. The 188 sites with missing housing data in 1980, 1990, or 2000 are not included in the subsequent analysis and hence are excluded from this figure. The vertical line at 28.5 represents the cut-off that determined eligibility for placement on the NPL.

Figure 5: Probability of Placement on the NPL by 1982 HRS Score



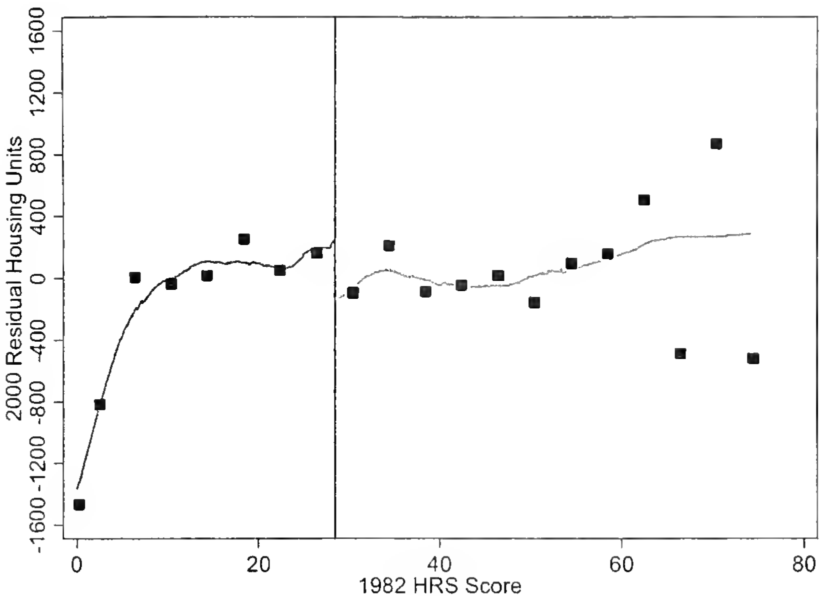
Notes: The figure plots the bivariate relation between the probability of 2000 NPL status and the 1982 HRS score among the 487 sites in the 1982 HRS sample. These plots are done separately for sites below (dark colored line) and above (light colored line) the 28.5 threshold. They come from the estimation of nonparametric regressions that use Cleveland's (1979) tricube weighting function and a bandwidth of 0.5. The data points present the mean probabilities in the same 4-unit intervals of the HRS score as in Figure 4. See the text for further details.

Figure 6: 2000 Residual House Prices after Adjustment for Column 4 Covariates, 2-Mile Radius Sample



Notes: The figure plots the results from nonparametric regressions between 2000 residual housing prices from the 2 mile radius sample after adjustment for the covariates in the column (4) specification of Table 4 (except the indicator for a HRS score above 28.5) and the 1982 HRS scores. The nonparametric regressions use Cleveland's (1979) tricube weighting function and a bandwidth of 0.5. These plots are done separately for sites below (dark colored line) and above (light colored line) the 28.5 regulatory threshold. The data points are based on the same 4-unit intervals of the HRS score as in Figures 4 and 5. See the text for further details.

Figure 7: 2000 Residual Housing Units after Adjustment for Column 4 Covariates, 2-Mile Radius Sample



Notes: The figure plots the results from nonparametric regressions between 2000 residual housing units from the 2 mile radius sample after adjustment for the covariates in the column (2) specification of Table 8 (except the indicator for a HRS score above 28.5) and the 1982 HRS scores. The nonparametric regressions use Cleveland's (1979) tricube weighting function and a bandwidth of 0.5. These plots are done separately for sites below (dark colored line) and above (light colored line) the 28.5 regulatory threshold. The data points are based on the same 4-unit intervals of the HRS score as in Figures 4-6. See the text for further details.